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MONTEREY, CALIFORNIA

SYSTEMS ENGINEERING CAPSTONE PROJECT REPORT

THE DISTRIBUTED AIR WING

by

Cohort 20
Team Bravo

June 2014

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

A2AD	Anti-Access / Area Denial
AACER	Adaptive Conformal Electronic Scanning Array Radar
AD	Area Denial
AEGIS	Aegis Combat System
AGM	Air-to-Ground Missile
AMRAAM	Advanced Medium-Range Air-to-Air Missile
AO	Area of Operation
AOC	Area of Conflict
ASBM	Anti-Ship Ballistic Missile
ASCM	Anti-Ship Cruise Missile
ASD(R&E)	Assistant Secretary of Defense for Research and Engineering
ASEAN	Association of Southeast Asian Nations
ASM	Air-to-Surface Missile
AWACS	Airborne Warning And Control System
BMD	Ballistic Missile Defense
C4I	Command, Control, Communications, Computers and Intelligence
CAP	Combat Air Patrol
CAS	Combat Air Support
CDCM	Coastal Defense Cruise Missile
CDF	Cumulative Density Function
CEP	Circular Error Probability
CIWS	Close-in Weapon System
CNAF	Commander, Naval Air Forces
COA	Courses of Action
CONOPS	Concept of Operations
COTS	Commercial Off-the-Shelf
CRUSER	Consortium for Robotics and Unmanned Systems Education and Research
CSBA	Center for Strategic and Budgetary Assessments
CSG	Carrier Strike Group
CVE-X or CVE	Experimental Escort Carrier (U.S.)
CVLs	Light Aircraft Carriers
CVN	Nuclear Aircraft Carrier
CVW	Carrier Air Wing
DARPA	Defense Advanced Research Projects Agency
DAW	Distributed Air Wing
DAWO	Distributed Air Wing Operations
DCA	Defensive Counter-Air
DDG	Destroyer
DF-21	Dong-Feng 21

DMZ	Demilitarized Zone
DOD	Department of Defense (U.S. Government)
DOE	Design of Experiments
EAB	Expeditionary Advanced Base
EEZ	Exclusive Economic Zone
EM	Electromagnetic
EMALS	Electromagnetic Aircraft Launch System
EMCON	Emission Control
EO	Electro-Optical
ESOH	Environmental Safety Occupational Health
EW	Electronic Warfare
FFBD	Functional Flow Block Diagram
FFG	Frigate
FLIR	Forward Looking Infrared
FORESTER	Foliage-penetrating Reconnaissance Surveillance Tracking Engagement Radar
FT	Flight Time
GAMS	General Algebraic Modeling System
GPS	Global Positioning System
HUMINT	Human Intelligence
HVU	High Value Unit
ICOMs	Inputs, Controls, Outputs and Mechanisms
IDEF0	Integrated Definition for Functional Modeling
ILP	Integer Linear Program
IOC	Initial Operational Capability
ISR	Intelligence, Surveillance, and Reconnaissance
JASSM	Joint Air-to-Surface Standoff Missile
JATO	Jet-Assisted Take-Off
JMSU	Joint Marine Seismic Undertaking
LACM	Land Attack Cruise Missile
LCS	Littoral Combat Ship
LEO	Low Earth Orbit
LER	Loss-Exchange-Ration
LHA	Landing Helicopter Assault
LIDAR	Laser Imaging Detection and Ranging
LOC	Lines of Communication
LP	Linear Programming
LRASM	Long Range Anti-Ship Missile
LT	Long Ton
MANA	Map-Aware Non-uniform Automata
ME	Mechanical Engineering
MEU	Marine Expeditionary Unit
MILCON	Military Construction

MILP	Mixed Integer Linear Program
MOE	Measures of Effectiveness
MOP	Measures of Performance
MOTS	Military Off-the-Shelf
MOVES	Modeling Virtual Environments and Simulation
MRBM	Medium Range Ballistic Missile
MT	Maintenance Time
MTX	Missile-Truck Concept
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVAIR	Naval Air Systems Command
NPS	Naval Postgraduate School
NWDC	Navy Warfare Development Command
OCA	Offensive Counter-Air
OPNAV	Chief of Naval Operations
OR	Operations Research
OTH	Over-the-Horizon
PACFLT	Pacific Fleet
PC	Patrol Craft
Pd	Probability of Detection
Phit	Probability of Hit
Pk	Probability of Kill
PLA	People's Liberation Army
Pmk	Probability of mission kill
PRC	People's Republic of China
R & D	Research and Development
RAND	Random
RCP	Relative Combat Power
RCS	Radar Cross Section
RF	Radio Frequency
SAG	Surface Action Group
SAM	Surface-to-Air Missile
SATCOM	Satellite Communications
SCS	South China Sea
SE	Systems Engineering
SEA	Systems Engineering Analysis
SEA-20B	The Systems Engineering Analysis Cohort 20 Team B
SEAD	Strike Suppression of Enemy Air Defenses
SGR	Sortie Generation Rate
SIGNIT	Signal Intelligence
SOCOM	Special Operations Command
SOFA	Status of Forces Agreement
SRBM	Short-Range Ballistic Missile

SSG	Strategic Studies Group
SSK	Diesel powered submarine
SSN	Nuclear powered attack submarine
STOVL	Short Take-Off and Vertical Landing
TAO	Tactical Action Officer
TAT	Turn-Around-Time
TBD	To Be Determined
TLAM	Tomahawk Land-Attack Missile
TRL	Technology Readiness Levels
TSB	Tactical Strike Base
TSSE	Total Ship Systems Engineering
TTPs	Tactics, Techniques, and Procedures
UAS	Unmanned Aerial System
UAV	Unmanned Air Vehicle
UCAS	Unmanned Combat Aerial System
UCLASS	Unmanned Carrier Airborne Surveillance and Strike
UCAV	Unmanned Combat Air Vehicle
UN	United Nations
UNCLASS	Unclassified
UNCLOS	United Nations Convention on the Law of the Sea
USMC	United States Marine Corps
USN	United States Navy
VADER	Vehicle Dismount and Exploitation Radar
VLS	Vertical Launching System
VTOL	Vertical Takeoff and Landing
WSO	Weapons System Officer

EXECUTIVE SUMMARY

The U.S. Navy is currently the preeminent naval power in the world with the ability to control the seas and project power across the globe. However, as the service looks to the future, it must overcome two substantial challenges.

First, it must continue to operate against threats, symmetric and asymmetric, that aspire to surpass the United States' capabilities in the maritime domain. Today, these adversaries are employing weapons such as submarines, cruise missiles, and long-range anti-ship ballistic missiles to prevent access into critical areas and limit freedom of action once there. This strategy is known as anti-access and area denial (A2AD) (Department of Defense 2012). These actions drastically increase risk to the fleet as it performs its core missions.

Second, the U.S. Navy must meet this threat while operating within an increasingly difficult fiscal environment. Therefore, it must take a systematic look at its current force structure and devise new and innovative ways to operate more effectively and efficiently; reducing risk and fulfilling its mission of preserving freedom of the seas.

The Systems Engineering Analysis cohort class 20B (SEA-20B) at the Naval Postgraduate School (NPS) approached this challenge by exploring a concept called the "Distributed Air Wing (DAW) (Grund 2013)." This high level concept includes various methods to distribute and disperse naval air capabilities from its centralized location on an aircraft carrier. According to definitions presented to the team by the CNO's Strategic Studies Group (SSG), distribution involves taking the capabilities inherent to the air wing and distributing them among multiple platforms (Strategic Study Group Executive Member 2014). Dispersion involves taking the individual aircraft that make up an air wing and geographically dispersing them to multiple locations (Strategic Study Group Executive Member 2014). Both options offer viable methods to reducing risk.

SEA-20B offers the U.S. Navy three alternatives that fall under the concept of the DAW; the Dispersed Air Wing Operations (DAWO) concept, a seaborne unmanned

aircraft courier system (Sea Scout), and a carrier/land based unmanned air-to-air fighting vehicle (MTX).

These alternatives were evaluated using a model developed by the Team called the South China Sea Basing Optimization Model. The model optimizes the quantity and locations of Aircraft Carriers (CVNs), UAV Carriers (Sea Scouts) and Expeditionary Airbases (EABs) to cover specified mission sets in the South China Sea for minimal risk. Analysis shows that a combination of these alternatives in varying degrees will deliver the fleet's three most critical capabilities (ISR, Offensive/Defensive Counter Air, and Surface/Land Strike) at less risk than the current CVN/CVW force structure. Risk is measured in the exposure to enemy weapons' effects scaled by the number of personnel exposed to those threats. These results can be seen in Table 1.

Alternatives	Scenario Requirements: Optimal Solutions					
	Quantity			Cost (\$B)	Scaled Risk	Normalized Risk
	CVNs	EABs	Sea Scouts			
CVNs Only	2			21.9	3846	100%
CVN + Sea Scouts	1		1	11.6	1480	38%
EABs Only		22		31.0	1488	39%
EABs + Sea Scouts		10	3	16.0	724	19%
CVN + EAB + Sea Scouts	1	10	1	25.7	675	18%

Table 1. Optimal solutions for baseline mission requirements.

There are three efficient solutions for the model. One CVN and one Sea Scout offer the least expensive alternative to achieve a significant reduction in risk. For approximately \$5 billion more, ten EABs and three Sea Scouts offer an even greater reduction in risk. Finally, for an additional \$10 billion only a minor further reduction in risk can be achieved. Therefore, the first two alternatives offer the greatest return on investment. The force structure with only CVNs and the force structure with only EABs

are not efficient solutions because a greater reduction in risk can be achieved for a lesser total cost.

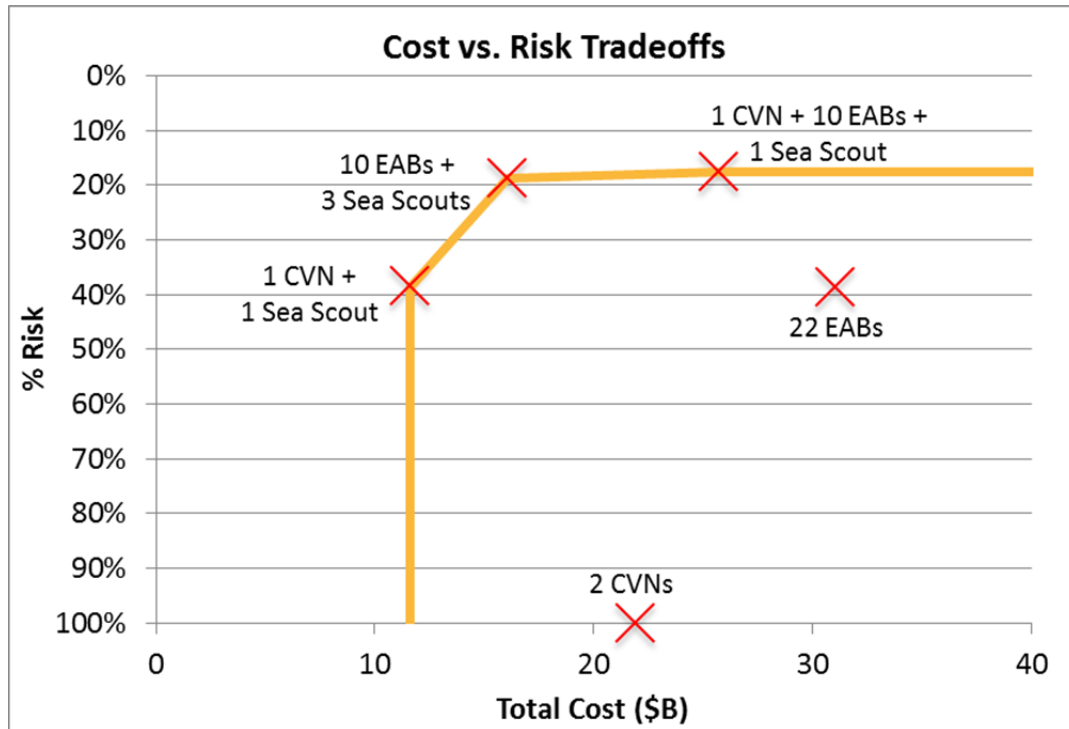


Figure 1. Cost vs. risk efficiency of alternatives.

Next, each of the three concepts, DAWO, Sea Scout, and MTX are briefly described and the key insights from analysis presented.

DISPERSED AIR WING OPERATIONS

DAWO involves dispersing the aircraft from the carrier air wing to land bases when it is operationally advantageous to do so. The use of dispersed basing complicates the enemy's targeting and greatly amplifies the resources required for the enemy to put the entire air wing out of action. Operating the CVW in this way reduces risk and allows the full spectrum of Naval Air capabilities throughout the battle space.

These basing options include small-scale Expeditionary Airbases (EABs) for Marine Corps STOVL aviation combat elements, Tactical Strike Bases (TSBs) which use dual-purpose highways as runways for conventional takeoff aircraft from the carrier air wing, and Dispersed Hubs consisting of civilian airfields with hardened and reinforced defenses. These basing options do not require the procurement of new hardware. They only require good relationships with the allied countries in the desired region and personnel with the expertise and the training required to construct such bases.

The pros and cons of each basing concept are analyzed in detail by the SEA-20B team. Significant advantages of DAWO are reduced vulnerability, increased deterrence, and enhanced partnership opportunities with regional nations. Confounding factors are logistical and maintenance complexity and more difficult command and control requirements.

The Team conducted simulations and analyzed the vulnerability and susceptibility of these bases to attack. Dispersed airbases are shown to be inherently less vulnerable than a CVN. They require significantly more ordnance to achieve neutralization. This is primarily a function of dispersed parking. When parked aircraft are separated by a distance equal to the lethal radius of the incoming warhead, a single missile can only damage a single aircraft. This stands in stark contrast to the damage a single warhead can cause to a CVW if it impacts a CVN flight deck. In addition to dispersed parking, camouflage and hardening provide additional vulnerability reduction.

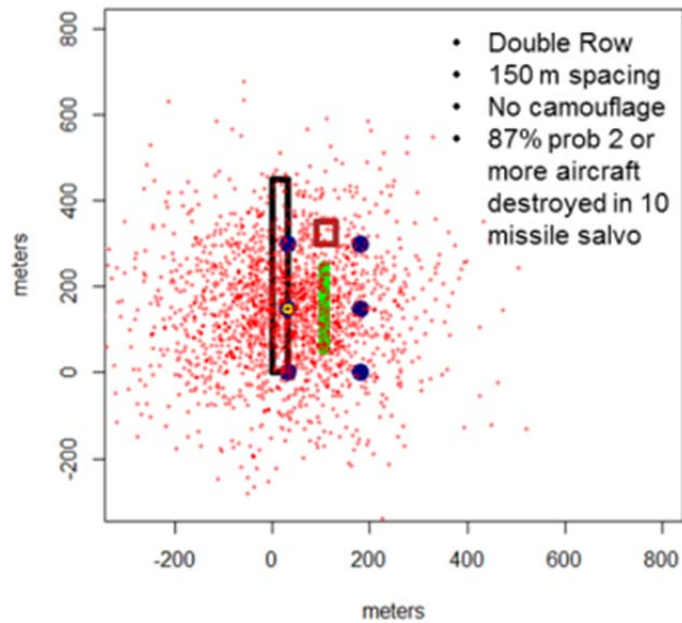


Figure 2. Monte Carlo simulation results: double row parking with 150 m spacing, no camouflage.

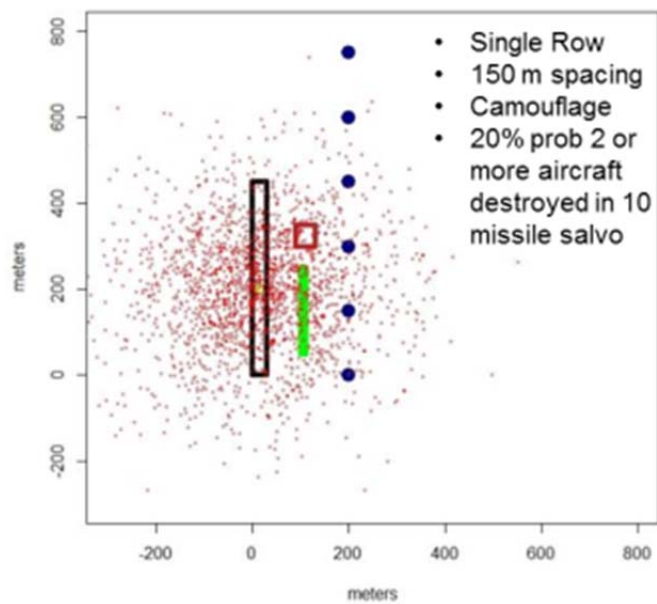


Figure 3. Monte Carlo simulation results: Single row parking with 150 m spacing, camouflaged.

SEA SCOUT

Sea Scout is a system-of-systems designed to meet the requirement of distributing airborne ISR, Land Strike and Surface Strike capabilities throughout the fleet. The team developed the concept by reengineering the Naval Air Warfare Center's Sea Vex concept. Sea Scout is comprised of two main elements: a small UAS courier ship and its embarked air wing of unmanned aerial systems. The system's purpose is to deliver persistent distributed capabilities wherever and whenever the fleet needs them the most.

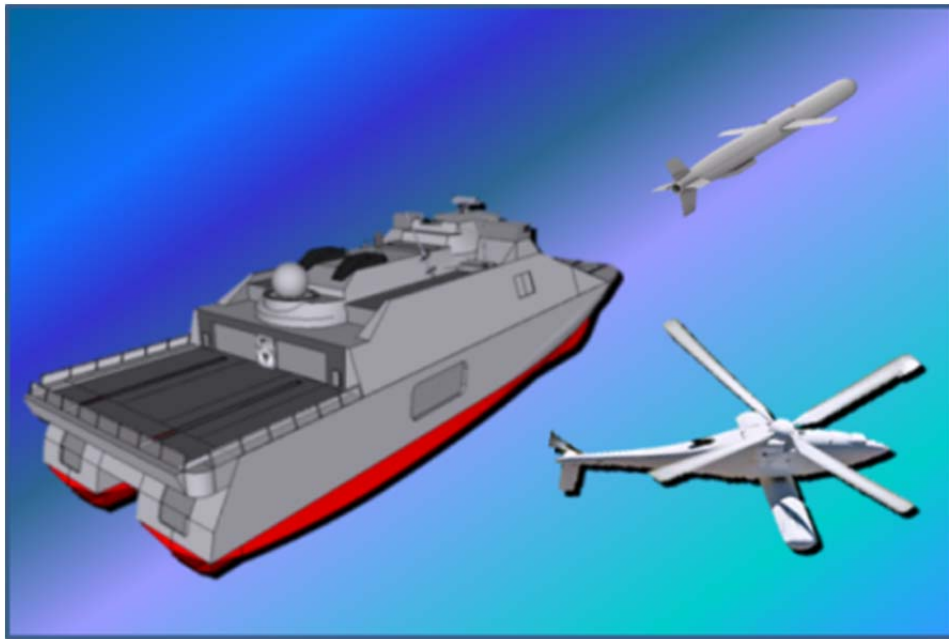


Figure 4. Sea Scout system components.

The UAS courier vessel, also known as an Escort Carrier (CVE), is about 1/3rd the size of a CVN, 1/8th the cost (including acquisition and operation support), and requires only 2% of the CVN/CVW crew. Its small size and speed of up to 50 knots, coupled with point defense capabilities and soft kill measures, make the vessel more difficult to target by A2AD threats.

As envisioned by SEA-20B, Sea Scout provides full spectrum ISR capability via the A160 Hummingbird, a rotary wing autonomous UAS platform currently in development by Boeing. While ISR is the Hummingbird's primary mission within the

concept, developing capabilities also include a limited capacity for Direct Attack, Communications Relay operations, and Precision Resupply applications. Use of the Hummingbird also provides the fleet with over-the-horizon detection and targeting capabilities that enable extended range anti-ship cruise missiles and land attack missiles to reach their full capability in dynamic targeting scenarios. The Hummingbird's capability is far superior to any platform of its type and weight class boasting a 222 knot maximum speed, a 2,500nm range, 20hr endurance, 2,500lb payload capacity and a full complement of integrated sensors.

Strike capability is designed into Sea Scout with the utilization of current and emerging state-of-the-art cruise missile technology via the Tactical Tomahawk Land Attack Missile (TLAM) and the Long Range Anti-Ship Missile (LRASM). These platforms are integrated into the system by the use of 14 Mk 57 next generation Vertical Launch Systems. With the Mk 57, Sea Scout brings a tailored mixture of up to 56 strike missiles to the fight.

Modeling shows that Sea Scout's additional firepower, when added to a Surface Action Group (SAG) consisting of three DDGs, results in significant improvement in results over a wide range of test cases. Table 2 lists the three test cases that were modeled. Case 1 represents a robust surface adversary comprised entirely of DDGs with superior area defense capability. Case 2 represents a group of small missile boat combatants with point defense only. Case 3 represents a mixed group of missile boats with DDGs that provide a moderate missile defense.

Blue Force Composition	Case	Red Force Composition
3 x Arleigh Burke DDGs 1 x Sea Scout	1	1 x Sovremenny DDG 2 x Type 52D DDGs 2 x Type 52C DDGs
	2	15 x Type 22 Missile Boats
	3	15 x Type 22 Missile Boats 2 x Type 52C DDGs

Table 2. Cases modeled.

Figure 5 displays the results of adding Sea Scout to the surface action group. In all cases, the additional firepower provided by Sea Scout resulted in an increase of the mean number of mission kills (at least 1 hit). In Case 3, the additional firepower overwhelmed the DDGs' area defense capability which tripled the salvo effectiveness.

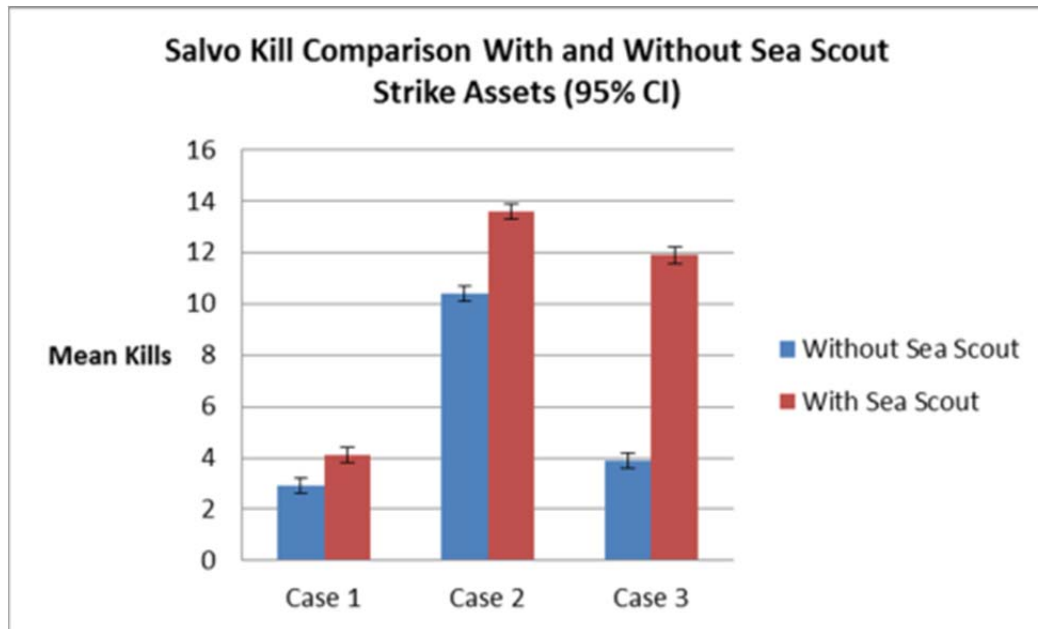


Figure 5. Sea Scout Strike Asset Effectiveness.

Sea Scout was designed with the capacity for growth. The CVE itself has space to integrate more platforms and the Hummingbird has sufficient payload to integrate additional sensors or weapons. Therefore, as UAS technologies improve, additional capabilities such as Electronic Warfare, Mine Warfare and Anti-Submarine Warfare can be added in later increments of the system.

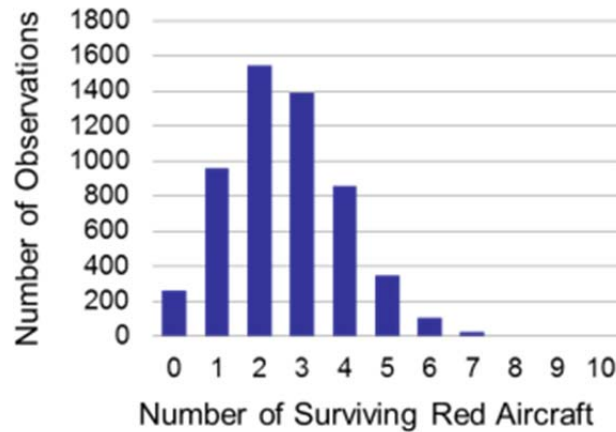
MTX MISSILE-TRUCK UAV

The SEA-20B MTX concept is a two-phase incremental system of unmanned aircraft capable of carrying air-to-air missiles to accompany manned aircraft on fighter missions and providing persistent on-station time for offensive and defensive counter-air missions. The MTX can be paired with a manned fighter for OCA or ISR missions or it

can be controlled by an operator from the ground for DCA missions. The concept of the MTX adds three important elements that will aid in closing the capability gaps that are present when the CVN is distant from the fight. First, it reduces risk to personnel by replacing manned aircraft with unmanned aircraft. Second, it increases the payload available to manned fighters allowing them to engage more targets. Finally, MTX increases combat range by reducing weight and adding extra fuel tanks.

Three options were considered for the MTX concept: an unmanned fighter (QF/A-18 or QF-16), an upgraded MQ-9 Reaper (MQF-X), and an X-47B UCAS. The unmanned fighter is the quickest and cheapest solution. It can fill the OCA capability gap as long as dispersed air bases are available for deployment. The upgraded version of the MQ-9 Reaper can fill the dedicated DCA role in protecting high value assets, but it requires costly modifications. Finally, the UCAS can provide greater range and endurance. Although these capabilities are critical in the A2AD environment, the X-47B is more expensive and requires a longer lead-time for procurement. Therefore, a phased-in approach based on technology readiness and operational necessity should be utilized when acquiring these systems.

To analyze this concept, a Monte Carlo simulation was designed to explore the benefits of adding unmanned air-to-air vehicles as a force multiplier to the DCA mission. The analysis shows that just two MTX platforms, outfitted with 10 AMRAAM missiles, facing an enemy raid of 10 aircraft have a 99.9% chance of destroying three or more aircraft, a 97% chance of destroying 5 or more aircraft, and a 75% chance of destroying 7 or more aircraft. The results of this simulation can be seen in Figure 6.



99.9% chance of destroying 1/3 of raid

97% chance of destroying 50% of raid

75% chance of destroying 2/3 of raid

Figure 6. MTX DCA Monte Carlo simulation results.

These simulation results demonstrate that a robust unmanned air-to-air missile platform can be utilized to attrite a significant number of adversaries as the first layer of a defense in depth configuration.

CONCLUSION

The Team concludes that nuclear powered aircraft carriers need not be eliminated from the U.S. Navy force structure. They provide unrivaled power projection capabilities. However, in order to ensure that their might can be brought to bear on future adversaries, the current force structure must be augmented by distributed capabilities that can mitigate risk inside of an A2AD environment. The analysis detailed within this report shows how the Distributed Air Wing concept can accomplish just that.

I. INTRODUCTION

A. PROJECT TEAM

The Systems Engineering Analysis 20B (SEA-20B) team comprises 17 students from four countries: the United States, Israel, Taiwan and Singapore. The team members have professional backgrounds that span a wide range of fields both inside and outside of the military. Specific naval warfare communities include naval aviation and surface warfare with platform experience that spans FA-18s, P-3s, H-60s, E-6Bs, cruisers, destroyers and amphibious assault ships. The international military officers bring in perspective from the Israeli Army Infantry, Republic of Singapore Air Force and Republic of Taiwan Army Acquisition Corps. On the civilian side, the Republic of Singapore is also represented by technology and acquisition professionals with working experience in several major programs and projects abroad.



Figure 1. Members of team SEA-20B: LCDR Vincent Naccarato, USN; ME5 Joong Yang Lee, Singapore; Major Meng Hsi Wu, Taiwan; Captain Ittai Bar Ilan, Israel; LT James Efird, USN; LT Benjamin Elzner, USN; LT Darrell Morgan, USN; LT Kayla Tawoda, USN; LT Evan Wolfe, USN; Wei Jun Goh, Singapore; Sok Hiang Loo, Singapore; Kok Wah Ng, Singapore; Chee Siong Ong, Singapore; Choon Ming Tan, Singapore; Hock Woo Tan, Singapore; Chung Siong Tng, Singapore; Kangjie Yang, Singapore.

The team also brings onboard the knowledge gained from each individual's specific course of study at the Naval Postgraduate School (NPS). There are five curricula represented by the overall group: Systems Engineering Analysis (SEA), Systems Engineering (SE), Operations Research (OR), Modeling Virtual Environments and Simulation (MOVES), and Mechanical Engineering (ME).

This diverse team with its wealth of knowledge and real-world experience provides the expertise necessary to tackle the broad and complex problem assigned by the project sponsor, OPNAV N9I (Warfare Integration). However, if subject-matter expert knowledge was needed outside of the team, that knowledge was easily accessible through the immense network of academic and operational professionals across the entire NPS campus.

One of the first tasks that the team tackled was to develop an organizational structure to allow for efficient operations. Aside from the three positions traditionally established for the SEA projects, that is, the project manager, lead systems engineer, and editor in chief, the team was further organized into three breakout teams with team leads in charge of each. Initially, the groups were utilized as breakout groups to focus on specific topics and processes within the Systems Engineering process. As the project matured, the groups were assigned specialty areas such as computer modeling and cost estimation. In the final phase, each group was assigned a solution alternative for focused analysis and conclusions. The final team organization is depicted in Figure 2.

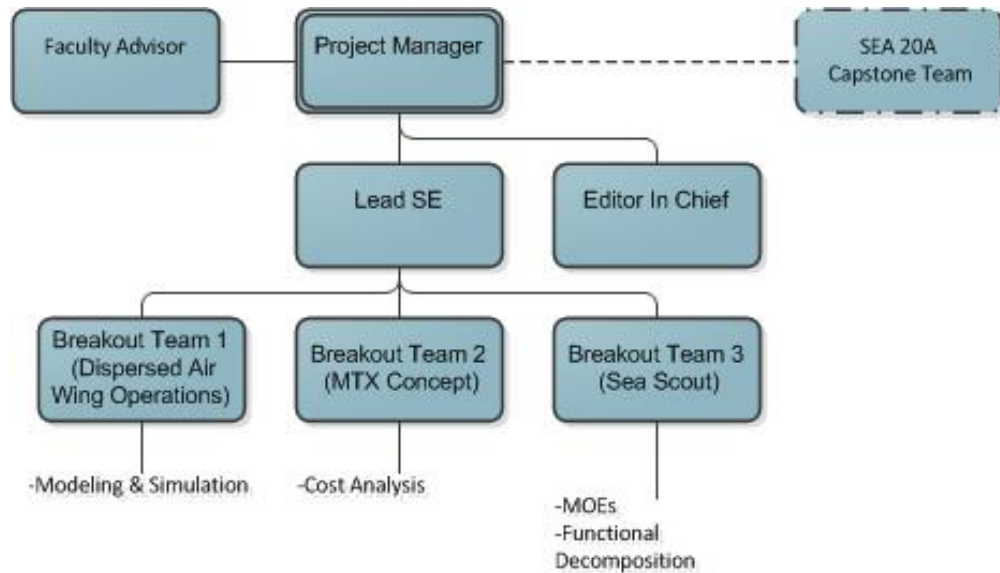


Figure 2. Project Team breakdown.

The organizational chart in Figure 2. depicts a broken line-connector to the SEA-20A Capstone Team whose focus topic assignment is the Distributed Naval Surface Force. This signifies the close relationship between the two projects and the integrated nature of fighting in the maritime domain. Throughout the project, integration efforts were made in order to acknowledge the fact that the naval surface and air forces cannot be successful without cooperation and coordination between the two entities.

B. CROSS-CAMPUS TOPIC EFFORT

It is important to note that the study topic assigned to the SEA-20 A and B cohorts, “Distributing Future Naval Air and Surface Forces,” was initially part of a campus-wide Warfare Innovation Continuum illustrated in Figure 3. This research thread garnered a significant amount of attention from several disciplines and organizations across the Naval Postgraduate School campus. The effort was developed and coordinated primarily through the Operations Research and Systems Engineering departments who fostered the interactions, discussions and overall cooperative efforts of both on- and off-campus stakeholders. The Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) also played a significant role in supporting and organizing focused forums on the topic.

One of the main benefits of working through the Warfare Innovation Continuum was the inclusion of focused and tailored quarter-long courses and activities dedicated to the exploration of the “Distributed Naval Forces” research topic. Specifically for the SEA-20 cohort, immersion into the problem and solution space began in July of 2013, when half of the team was enrolled in the Joint Campaign and Analysis class. It was in this class that campaign-level analysis tools and techniques were taught and directly applied to the topic within the context of a South China Sea Scenario. The class was also repeated during the January 2014 winter quarter, with a focus on an East China Sea scenario. Both iterations of the classes resulted in solution alternatives and insights that were further applied and developed during the SEA-20B Capstone effort.

The CRUSER warfare innovation thread, held in late September 2013 during the semester break known as Enrichment Week, allowed for further exploration of the problem and solution space by including diverse military officer students from across NPS curricula. This week-long event began by presenting several new technologies to focus groups that could potentially have an impact within the solution space. Groups were then divided to tackle the problem by utilizing free-flowing brainstorming sessions to apply solutions to the problem. Several aspects of the CONOPS that were first conceived during this Enrichment Week activity have been included in the final solution of this study.

During the fall quarter, beginning in October of 2013, the SEA cohort explored the problem-space through the OR department’s *Introduction to Wargaming* course, where again, the problem was given focused attention for an entire semester. The students developed a wargame that explored the problem and solution space from the Red (enemy) force perspective. Subject-matter experts on China from the Naval Postgraduate School as well as Commander, Pacific Fleet staff were utilized in the Red cell to help understand how China might react to specific solution alternatives. This exercise provided valuable information that helped shape the understanding of the second- and third-order effects of applied solutions as well as an overall better understanding of the problem-space from a potential adversary’s point of view.

There were also several research activities within the continuum that SEA team members were not directly involved with but were able to gain direct benefits from. This includes the Total Ship Systems Engineering class' focused effort on a CVE design, which is an integral part of the Sea Vex system concept that will be discussed in Chapter VIII. The resulting product was used as the SEA-20 baseline design and cost estimation for the ship aspect of the system. Also, the Joint C4I class focused on Sea Vex command and control alternatives, which provided important insight into the control aspects of UAS designs developed within this study.

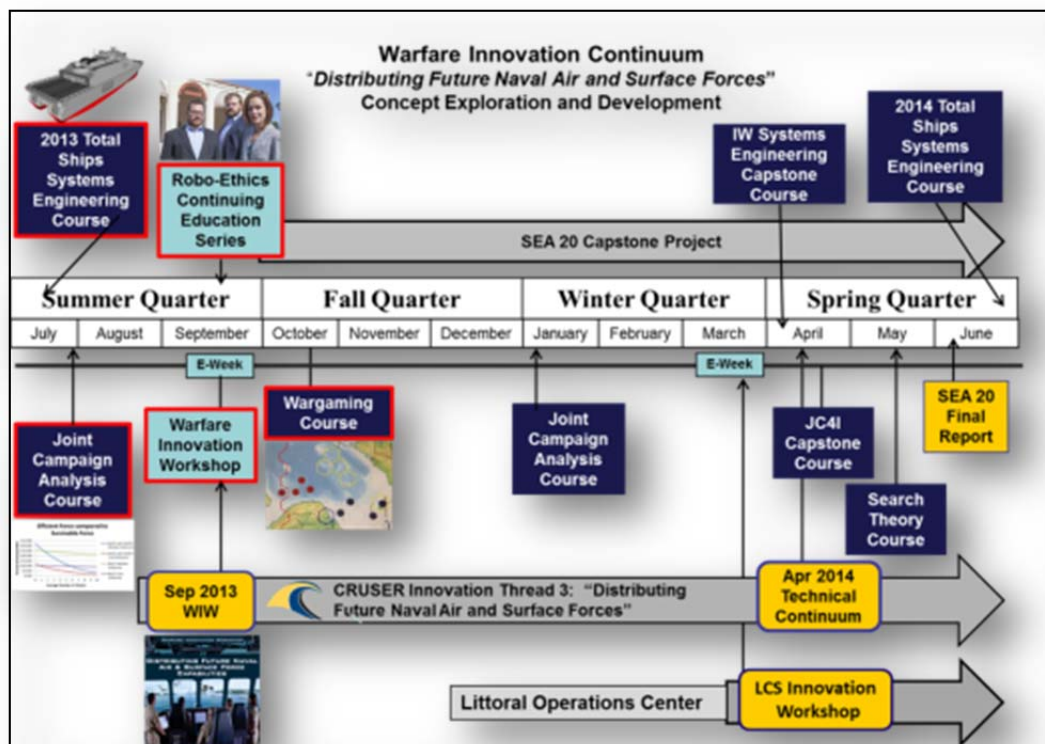


Figure 3. Warfare Innovation Continuum cross-campus effort timeline.

Figure 3. depicts the cross-campus effort that took place over the course of one year at NPS. SEA-20B members specifically took part in the Joint Campaign Analysis Course (one quarter), the Warfare Innovation Workshop (one week), and the Wargaming Course (one quarter) as part of the Systems Engineering Analysis curriculum offered at NPS.

C. SYSTEMS ENGINEERING PROCESS

The following approach represents the tailored Systems Engineering Process developed and refined throughout the project.

1. Approach

The team's approach on this project consists of applying the core processes and analysis tools learned in the Systems Engineering Analysis curriculum and previous educational courses in conjunction with real-world operational experience and hands-on research. SEA-20B constructed a tailored systems engineering process to guide the progress, analysis, and report deliverables with the final solution being a recommendation for a Distributed Air Wing Force Structure and Concept of Operations (CONOPS) for future integration into a larger system of systems to address the stakeholder's effective need. This effective need is discussed later in the report.

2. Method

In contrast to a traditional individual thesis, a capstone project requires special attention and coordination among all team members to critically analyze and effectively synthesize all the information produced throughout the process. As mentioned earlier, to accomplish this, the team designated a project manager and SE team lead, as well as an editor-in-chief, who then divided the team up into three major teams and designated a team leader for each. In the project's early stages, the team conducted all-inclusive brainstorm sessions and subject matter expert presentations. To keep the research on schedule over a course of nine months, the online management tool known as "Redmine" (Redmine 2014) was utilized to assign tasks to team members with clear instructions and deadlines. For data and information management, the online information "cloud-tool" known as DropBox.com was utilized. Weekly meeting minutes were recorded by the

editor-in-chief and posted each week to keep the team and advisor up-to-date on the progress of the project. In the later stages of the project, each sub-team met weekly to complete project tasks and work on deliverables. Milestones for the project were in the form of two progress reviews and a final project review that were scheduled, presented, and video recorded for the stakeholders, advisors, and fellow students at the NPS. After each review stakeholder and advisor feedback was gathered and critically applied to the project. Figure 4. is a snapshot of the project manager Gantt chart that was used to track the progress of the project.

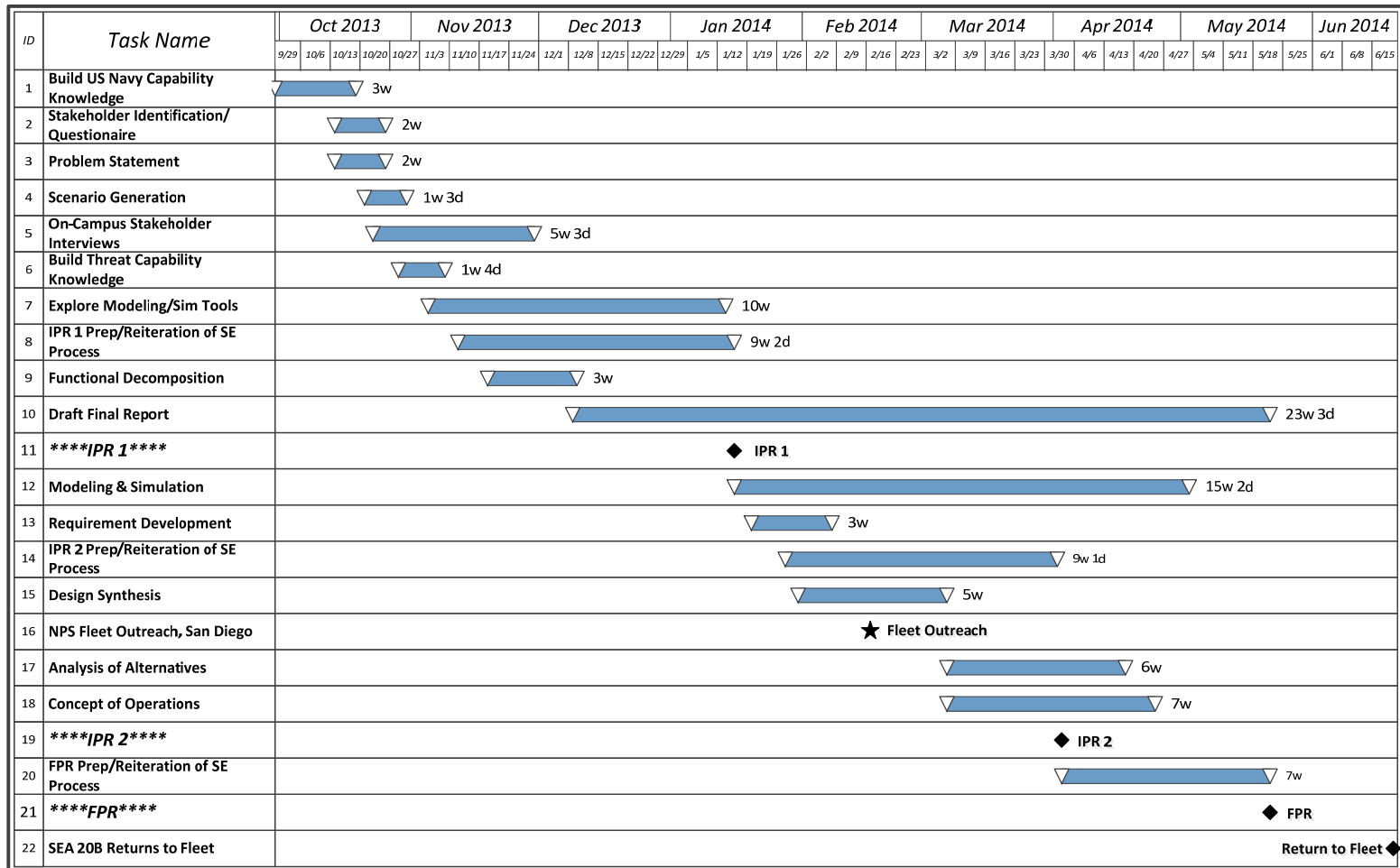


Figure 4. SEA-20B Gantt chart.

3. Tailored Systems Engineering Process

The systems engineering (SE) process that was implemented for the project was a tailored process that was sequenced and iterated to fit the team's specific project approach and requirements but still utilized the traditional SE methodologies learned. Figure 5 is a diagram of the team's Tailored SE Process Model.

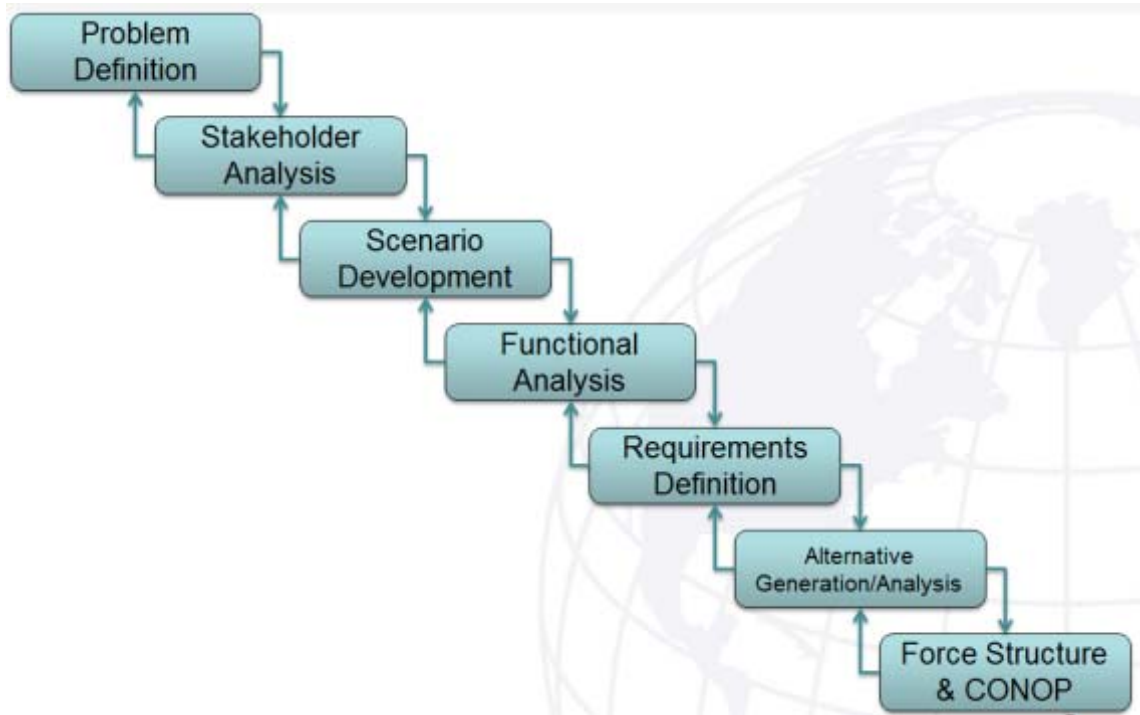


Figure 5. Tailored systems engineering process.

The team began with a complete Needs Analysis that included a thorough stakeholder analysis and problem statement refinement. With the Needs Analysis in progress the team also began completing background research on the assigned topic in order to facilitate scenario development. With a more defined scope and information on the operational environment in which to focus efforts, the team began a complete functional analysis of military forces' missions and capabilities necessary in order to achieve Sea Control. After many iterations of this analysis, the team was able to define the high-level requirements and measures of effectiveness and performance by examining the capability gaps in functional decomposition. Next, the team generated alternatives from which three future concepts were explored further to determine their feasibility and

suitability in the Distributed Air Wing solution architecture. Numerous qualitative and quantitative analyses were conducted to determine multiple different force structures and CONOPs that achieve the required mission effectiveness and reduce risk in the scenario. From here, the team determined sets of solutions to the effective need by taking into account the cost of each force structure alternative. The final recommendation includes an integrated force structure that addresses the stakeholder's effective need with a trade-space analysis in terms of risk and cost.

II. NEEDS ANALYSIS

A. TASKING STATEMENT

The tasking statement for the project was provided in a memorandum to the SEA-20B cohort from Professor James Eagle, Chairman Systems Engineering Analysis Curriculum dated 19 July 2013. The specific tasking was formulated from a topic of interest by the Naval Warfare Development Command and assigned through OPNAV N9I, the curriculum sponsor. The statement reads as follows:

Design a fleet system of systems and concept of operations to employ naval air assets in a range of missions to augment naval operations or conduct specified tasking in the 2025–2030 timeframe and beyond. Consider manned and unmanned air systems to execute direct support to the naval missions across the kill chain spectrum within a distributed air wing concept. For example, consider missions of future surface ship squadrons operating outside the CVN/CVW umbrella in sea control contested environments, and also more traditional strike and sea control missions integrating CVW manned and unmanned systems. Generate requirements for unmanned and manned aircraft and their sea bases by considering a range of future CVN and CVEX alternatives, ensuring each strike platform can execute its own kill chain regardless of the EM environment. Evaluate the value of distributing the air wing’s capabilities across the fleet and land-based facilities, to complicate an adversary’s offensive targeting and defensive measures. Consider current fleet structure and funded programs as the baseline system of systems in developing these concepts of operations, then develop alternative architectures for platforms, manning, command and control, communication/network connectivity, and operational procedures. Address the costs and effectiveness your alternatives.

B. STAKEHOLDER ANALYSIS

Identifying, conversing with, and analyzing the needs of project stakeholders are primary tasks within the Stakeholder Analysis process. The stakeholders’ direct involvement in the understanding of the problem space added valuable insight to the team throughout the entire process. Given the wide scope of the project, the initial list of potential stakeholders ranges from high level entities such as OPNAV and NAVAIR, to the war fighters and support elements, at the tactical level. Analysis and discussions among the team concluded with the development of the following Expanded Stakeholder

Diagram and Focused Stakeholder Depiction along with their level of influence on the project in Figure 6 and Figure 7.

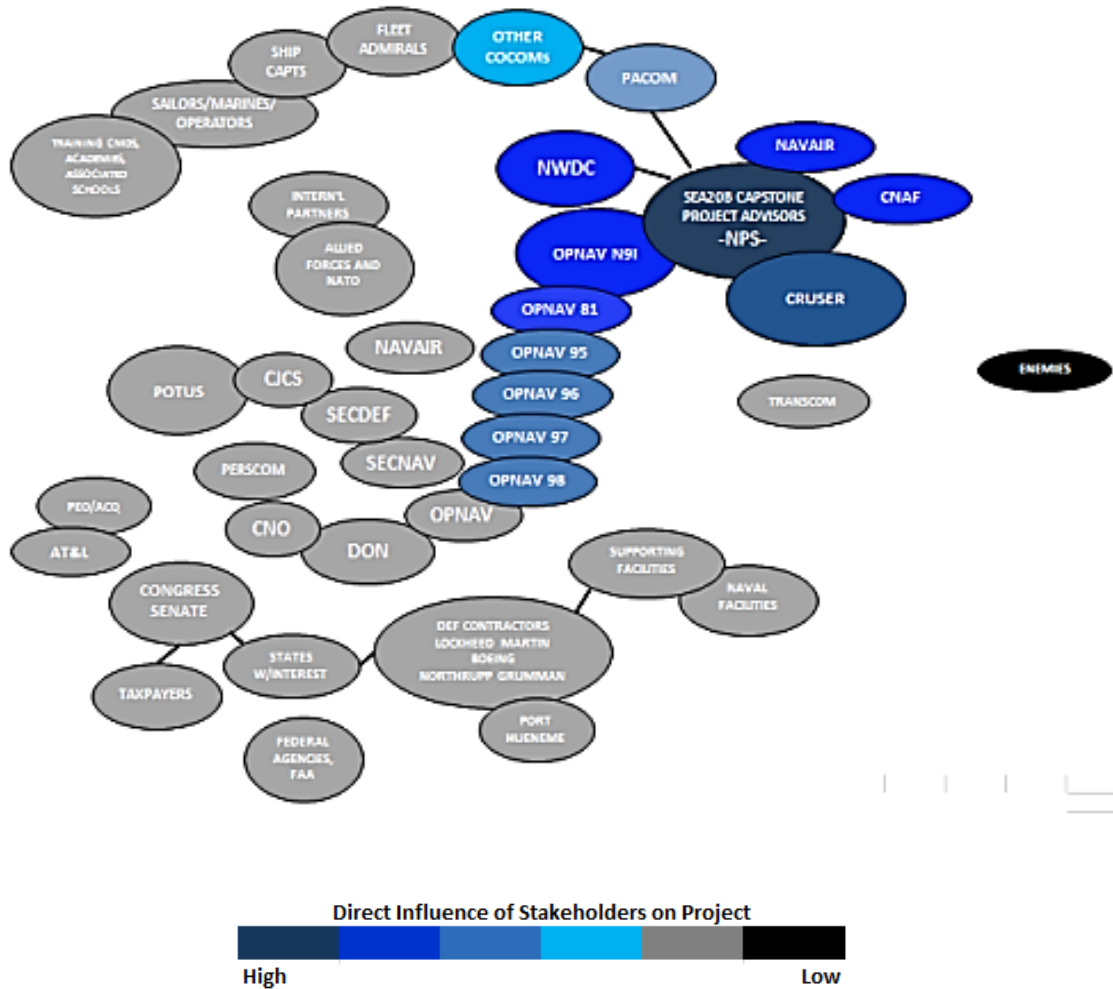


Figure 6. Stakeholder diagram.

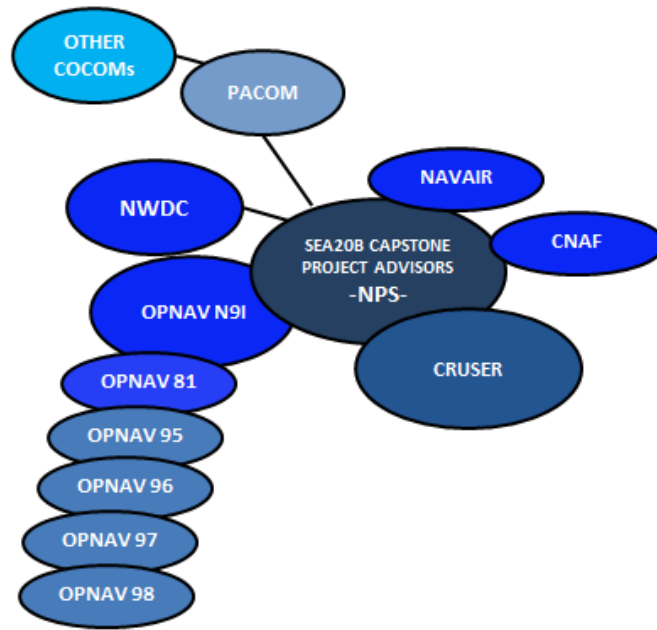


Figure 7. Focused stakeholder depiction.

As the graphics above depict, starting with a broad top-to-bottom look at the possible stakeholders resulted in a fairly large amount of candidates. While most of the stakeholders listed are viable when considering 2nd- and 3rd-order relationships, it became apparent that only a few met the criteria of being “key stakeholders”—those holding a high level of interest and direct influence in regard to the project topic and the SEA-20B analysis and results. Given that criteria, key stakeholders were identified in Figure 8 and are summarized below.

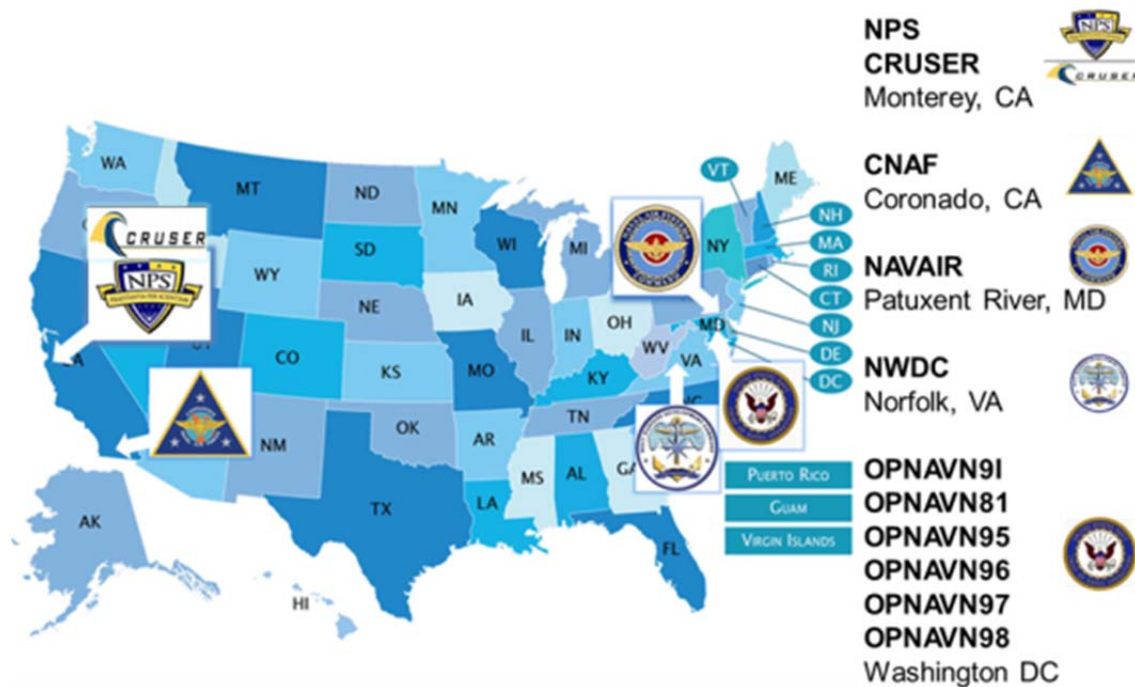


Figure 8. Stakeholder Geographical Map.

1. Key Stakeholders Identified

- NPS – Naval Postgraduate School, Monterey, CA

The Naval Postgraduate School is a key stakeholder in that it is home to the Systems Engineering Analysis program as well as the cross campus cohorts who have dedicated academic resources to this project. Also, NPS houses a collective of expertise that can support nearly every domain of study pertinent to the project. Most importantly, NPS provides a robust source of operators and leaders ranging from junior to senior level officers with tactical, operational and strategic experience. This allows SEA-20B to have convenient access to tip-of-the-spear knowledge across the military spectrum.

- CRUSER – Monterey, CA

The Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) is an example of one of the outstanding resources available at NPS (Stein 2003). With its roots seated in being “a collaborative environment for researchers,

industry, students, and defense personnel interested in all aspects of employing unmanned systems in an operational environment now and in the future,” collaboration and sharing information between the CRUSER network of research associates and SEA 20B was deemed vital to the project given the inclusion of current and future unmanned system technology inside of the team’s scope.

- CNAF – Coronado, CA

Commander, Naval Air Forces (CNAF) is Type Commander for all U.S. naval aviation units (Commander, Naval Air Forces 2014). CNAF is responsible for manning, training, equipping and maintaining aviation assets as well as providing operationally ready squadrons and aircraft carriers throughout the fleet (Commander, Naval Air Forces 2014). Given the scope of the Distributed Air Wing topic and the effective need to develop a new Naval Air Force structure, CNAF is a key stakeholder in the SEA project.

- NAVAIR – Patuxent River, MD

As the Naval Air Systems Command (NAVAIR) responsible for full life-cycle support of naval aviation aircraft and related weapons systems (Dunaway 2012), NAVAIR has a high level of influence and insight in regard to the project solution space. Given the utilization of alternatives in the early conceptual phase as well as the potential to reconfigure current systems in the solution space, the organization was able to provide insight and guidance as the team designs air related material solutions. The organization is also a valuable body of knowledge in regard to the acquisition process of naval air vehicles and weapons systems that comprises the vast amount of possible solution alternatives.

- NWDC – Norfolk, VA

The Naval Warfare Development Command is responsible for coordinating the development of concepts, doctrine, lessons learned and experimentation in direct support of the Fleet (Navy Warfare Development Command 2014). NWDC presented the Distributed Air Wing topic to the SEA-20B team and is directly connected to the project

through N9I. As a topic that the command is exploring within its own ranks, NWDC has a vested interest in the insights and analysis that will come out of the SEA-20B project.

- OPNAV – Washington, D.C.

Within the Office of the Chief of Naval Operations, there are several stakeholders that have been identified as potentially having a high interest in the Distributed Air Wing project (Global Security 2014).

OPNAV N9I – OPNAV N9I is responsible for Warfare Integration and is the SEA program sponsor. Mission success within the maritime environment relies heavily on integration between air, surface and subsurface units and was therefore a paramount consideration as the team developed a system of systems that fights in cohesion across the spectrum of naval warfare.

OPNAV N81 – OPNAV N81 is the assessment division within OPNAV responsible for conducting capability and campaign analysis throughout the Navy. The relationship with N81 undoubtedly helped align the team's analytical processes with the standards, tools and techniques recognized by DOD analysts and decision makers.

OPNAV N95, N96, N97 and N98 - As previously mentioned, the Navy fights as an integrated force. While the primary focus of the project is centered on air warfare capabilities, the inclusion of all warfare branches was prudent as the team explored the interaction that air capabilities have throughout each branch. Each major naval warfare area has had a direct influence on the different force structures that were designed and later analyzed to meet stakeholder requirements. Therefore, the inclusion of the OPNAV warfare branches OPNAV N95 (Expeditionary Warfare), OPNAV N96 (Surface Warfare), OPNAV N97 (Undersea Warfare), and OPNAV N98 (Air Warfare) as key stakeholders was necessary.

2. Stakeholder Interviews and Insights (Military On-Campus)

Initially, stakeholder interviews were conducted with Naval Postgraduate School on-campus personnel. Focusing on this group provided a key benefit in that it allowed easy access to highly experienced military professionals without a direct connection to the project that could look at the problem with a fresh set of eyes compared to stakeholders already heavily invested in the problem and solution. The personnel sought out for interview were senior level officers, both active duty and retired with experience across three warfare areas; Surface Warfare, Undersea Warfare and Air Warfare.

In regard to the tasking statement, all stakeholders agreed that the underlying problem stemmed from advanced A2AD threats placing High Value Units (HVUs), specifically the Nuclear Aircraft Carrier (CVN), at risk of loss in several areas around the world. U.S. fiscal volatility was also echoed as part of the problem in that the possibility of shrinking defense budgets, if and when that comes to fruition, will likely result in the reduction of force size and assets.

In most cases, discussions that logically started with cost, given the topic of fiscal uncertainty, quickly turned into discussions of value. Time and again, it was pointed out that while U.S. systems employed today do have a substantial monetary cost, their value comprises much more than a price in dollars. This is especially true when considering different stakeholder perspectives. For example, while entities who pay for these systems view HVUs through the lens of cost, to the warfighter, the capability a system brings to the fight is far more important than the system's price tag.

C. PROBLEM STATEMENT DEVELOPMENT

The team began the SE Process model by defining the problem and refining it into the stakeholder's effective need. After a detailed examination of the tasking letter along with clarification received from primary key stakeholders the team framed the assignment into the initial problem statement in Figure 9.

Problem Statement: *Design a fleet system of systems and concept of operations to employ naval air assets in a range of missions to augment naval operations or conduct specified tasking in the 2025-2030 timeframe and beyond. Consider manned and unmanned air systems to execute direct support to the naval missions across the kill chain spectrum within a distributed air wing concept.*

Figure 9. The initial Problem Statement.

Once the team was able to capture the tasking into a more precise problem definition, the process of solving began by asking, “Does the U.S. Navy actually need a new naval air wing force structure?” Through initial research the team found that the use of an Anti-Access / Area Denial (A2AD) strategy by the enemy presents a great threat to U.S. forces as they are currently configured (Krepinevich, Watts and Work 2003). This strategy threatens the United States’ current maritime superiority as well as the ability to protect its national interests. The effect of an A2AD threat to aircraft carriers and the air assets it employs is too great to ignore and is a risk that must be mitigated. The lack of an effective over-the-horizon targeting asset for aircraft carriers and the carrier air wing is also an important factor. This threat is growing during a fiscally challenging time and alleviating costs was a critical influence on how the team would attack this problem. All of these factors were taken into account and further researched (as discussed in Chapter III of the report) when the team defined the problem and further refined it for this project.

1. Scope

The tasking statement and subjects researched by the Team include such a wide range of subjects that scoping the study effort was required. It was critical to determine what was within the scope of the project and what lies outside of the scope.

a. In Scope

The subjects determined to lie within the scope of this project include:

- 2020s timeframe
- Naval manned aircraft, both current and future designs
- Unmanned aircraft suitable for naval use. This includes both military and commercial UAVs
- All ships capable of launching or engaging aircraft
- Marine Corps assets including aircraft and amphibious ships
- ISR, offensive and defensive counter-air, and strike missions including both land and maritime targets
- Future threats including ballistic missiles, cruise missiles, aircraft, submarines, and surface ships
- Technology with a Technology Readiness Level (TRL) three or higher
- Cost estimations for force structure alternatives

b. Out of Scope

The subjects determined to lie outside of the scope of this project include:

- Nuclear conflict
- Recommendations for U.S. Air Force future force structure
- Air Force basing recommendations
- U.S. submarine force structure recommendations
- Detailed logistic analysis
- Detailed analysis of cyber warfare threats
- Specific network requirements for command and control
- Nonmaterial solutions such as training and doctrine
- Determining specifically which countries would be political allies or have Status of Forces Agreements in the 2020s
- Ballistic missile defense recommendations
- Amphibious assaults

Many of these topics are crucial to the success of any naval force structure in the future. The Team discussed all of these subjects and their effects on the force structure were qualitatively considered. However, due to the time and classification constraints placed on the Team not all topics of interest could be addressed thoroughly. The subjects listed above are topics that should be addressed in future thesis and capstone work.

2. The Refined Problem Statement – The Effective Need

Below are the two core aspects of the problem statement that were identified by the team to be most important and were used as guiding issues for the rest of the project processes. From this refined perspective the team was able to derive the effective need for the project.

1. Emerging advanced A2AD threat capabilities introduce unacceptable risks to the CVN/CVW system that, if not mitigated, will result in the loss or reduction of naval air capability in contested waters.

2. The volatile U.S. fiscal environment severely constrains the Navy's ability to develop and sustain material solutions to this problem.

The Effective Need: *The U.S. Navy's effective need is a new Naval Air Force structure and concept of operations that integrates unmanned air systems (UASs) with current Navy systems in a way that maintains or exceeds current mission effectiveness while reducing the risk involved with operating under an A2AD umbrella.*

Figure 10. The Effective Need.

III. BACKGROUND AND RESEARCH

A. KEY CHALLENGES OF THE A2AD ENVIRONMENT

To help fully understand the A2AD threat environment, a threat hierarchy of plausible enemy A2AD threat actions and intentions was created. Part of the process of identifying capability gaps and developing solutions is becoming more aware of the adversary's perspective and the capabilities they can and would employ to create an A2AD threat environment. In 2003, the Center for Strategic and Budgetary Assessments (CSBA) defined anti-access as "enemy actions which inhibit military movement into a theater of operations," and area denial operations as "activities that seek to deny freedom of action within areas under the enemy's control" (Krepinevich, Watts and Work 2003).

The A2AD functional hierarchy defines the major categories of functions and tasks that make up a robust anti-access/area denial environment threatening the U.S.'s entry into and operation within a specific region.

First, the primary kinetic capacity to achieve anti-access is a large ballistic missile force made up of both DF-21-type and land-based Anti-Ship Ballistic Missiles (ASBMs) designed to attack large critical targets such as the nuclear powered aircraft carrier as well as naval and air bases (McCarthy 2010).

Next, to achieve area denial, the enemy's capabilities must primarily consist of kinetic counter-maritime and counter-air systems such as submarines with torpedo and ASCM capabilities and bombers with air-to-surface and air-to-ground capabilities to compound the layered area denial threat umbrella (McCarthy 2010).

In addition, non-kinetic space and cyber systems are ready to be employed that are specifically designed to disrupt information flow and U.S. power projection further complicating the environment. As stated in a study from the Center for Strategic and Budgetary Assessments, "Even more disconcerting is the growing proliferation of national and commercial satellite services and missile technology. Increased access to these satellite services will allow even regional rogue states both to pre-target key fixed facilities and to monitor U.S. deployments into forward bases," (Krepinevich, Watts and Work 2003).

Figure 11 depicts the A2AD Threat Functional Hierarchy created by the team to clearly outline what the enemy threat is trying to achieve.

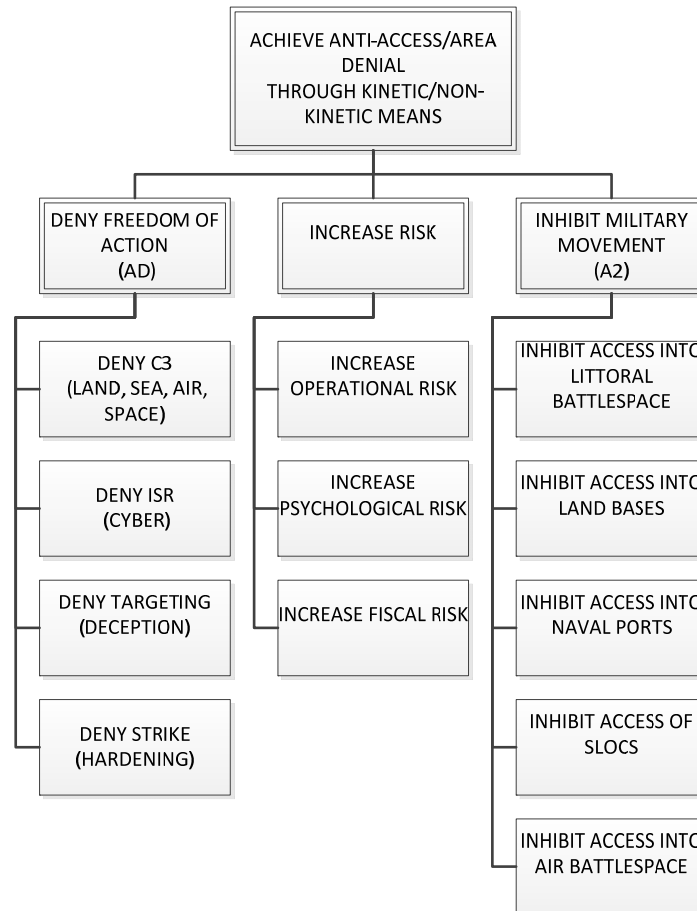


Figure 11. The adversary's A2AD functional hierarchy.

B. INITIAL FORCE STRUCTURE CONSIDERATIONS

As demonstrated in the previous section, the team analyzed the initial problem statement critically and iteratively taking into account the inputs from the various stakeholders. This iterative process allowed for the team to adjust the boundaries of the problem space as more understanding was gained. One issue brought to light throughout this process of problem refinement was that although the topic was called “Distributed Air Wing,” which sounds singular in nature, this project was not just a simple one-for-one swap of systems or stand-alone system development project; rather, this project represents the development and combination of concepts that the Carrier Strike Group

(CSG) can incorporate into its force structure in order to combat the A2AD threat environment. This is, in part, due to the fact that naval air assets rely heavily on surface assets to support their air capability and vice versa.

What is apparent is that every domain has the potential to affect every part of the CVW structure and mission. If an enemy submarine were to destroy and sink the CVN that the CVW used as its base of operations, then the air capability as well as the significant command and control capability of the CVW would be lost. If the enemy used sophisticated Electronic Warfare (EW) against the airborne or space-based communications assets that support the CVW, then data links integral for CVW operations could be severed. The team considered what effect each domain has on a carrier air wing and how adversaries could use those domains directly or indirectly to affect the core and supporting elements of the carrier air wing and ultimately the CSG.

As indicated in the tasking letter and emphasized by the stakeholders, the A2AD environment is one of the most complex and challenging environments for U.S. forces. Most anti-access/area denial threats can be divided into two types: kinetic and electronic. Kinetic weapons can be used directly to gain air, land, and sea superiority, or merely the threat of their use can be used to deny an area. The specific kinetic threats to the Fleet include weapons such as anti-ship ballistic missiles (ASBMs), anti-ship cruise missiles (ASCMs) torpedoes, mines, and new anti-aircraft missiles. As will be discussed later in the report, the team tailored the CVW integration requirements around this need to operate within or close to the A2AD kinetic threat environment.

The team also focused on evaluating the electronic threats that comprise the A2AD environment. Specifically, how increased capabilities to limit the use of information transmitted throughout the radio frequency (RF) spectrum, could affect U.S. mission accomplishment. The U.S. military, especially the Navy, has recently focused many resources on network integration which relies on secure transmissions between air, surface, sub-surface, and space assets. However, these transmissions can become vulnerable to spoofing, hacking, and jamming by the enemy in an A2AD environment. A persistent electronic A2AD threat environment could severely degrade a CVW's C4I capabilities. These electronic threat technologies are becoming more attainable for

adversary state actors, and thus need to be accounted for in terms of resilience and redundancy while proposing a solution to the CVW force structure.

IV. SCENARIO DEVELOPMENT

A. OPERATIONAL SCENARIOS

Scenario development was a part of the early Systems Engineering process in order to demonstrate a variety of situations that could develop across the entire globe in which the U.S. would most likely be called upon to assist, defend, deter, and/or strike. After the development of the following scenarios each one was analyzed in terms of the mission capabilities needed, weapons/warfare required, and finally environmental and geo-political factors.

1. Scenario 1 – A2AD Operations

Summary: Maritime and aerial maneuvers and staging in the South China Sea, a recognized A2AD environment, culminating in small marine landings in support of local allies.

Main reason to include scenario in analysis:

Large Joint Task Force operations in an extreme A2AD environment are a continuing crucial element of American power projection when battling away from friendly shores.

Possible scenario:

The conflict portrayed in this scenario begins by an aggressive move by the Chinese government in the South China Sea. This much contested body of water has large strategic and economic importance and is bordered by China, Taiwan, Indonesia, the Philippines, Malaysia, Brunei, Vietnam and Singapore, all of which have claims to some islands in the ocean. The ownership of some of these islands is contested by China and aggressive behavior is a likely source of a military flare-up involving U.S. armed forces.

The scenario begins by China asserting its claims over the entire Spratly Islands archipelago, currently claimed by China, Taiwan, Vietnam, The Philippines, Malaysia and Brunei. The aggressive expulsion of all non-Chinese military forces from the islands

ensues leading to increased tension between China and other local nations. A series of small scale naval battles occur between China, Vietnam and Malaysia. The series of battles, while being decided consistently in favor of the Chinese, end in the sinking of a Type 054A Jiangkai II Frigate by a Vietnamese anti-ship cruise missile (ASCM). Following the sinking China declares a blockade of the South China Sea. After requests from regional allies, the President of the United States decides to intervene to ensure freedom of the seas.

The United States executes war at sea, while maintaining diplomatic efforts to assure all sides that wartime action will not be taken against inland targets. Despite efforts to forestall military actions, Chinese ASCMs are fired from land-based military facilities on the Paracel Islands towards American warships. The U.S. establishes expeditionary airbases in allied territory and begins preparations for amphibious landings on all major archipelagos in the South China Sea. The scenario culminates in opposed amphibious action along with allied nations, while limited scope naval battles are fought at sea. Figure 12. depicts the South China Sea and the geographic region where this scenario takes place.



Figure 12. South China Sea with Paracel and Spratly Islands outlined (from University of Texas Libraries 2014).

2. Scenario 2 – Precision Strike Campaign

Summary: Increased tensions over the nuclear weapons program in Iran force the United States to conduct a precision strike campaign aimed at strategic and nuclear targets throughout Iran.

Main reason to include scenario in analysis: Medium-scale precision strike campaigns have been the most likely form of intervention by the international community facing renegade nations.

Possible scenario: The Iranian government has been developing nuclear weapons under the guise of nuclear power research and development for well over a decade. This program has caused tension between world powers and Iran, whose strategy has been to deny military ties to the nuclear program while biding for time. The tensions in this matter have been intensifying as intelligence agencies report that the extreme fundamentalist regime approaches its goal of becoming a nuclear power.

In this scenario the U.S. leads a UN Security Council resolution to blockade Iran as final leverage against its advancing nuclear program. A U.S. carrier group in Bahrain sets sail towards the Gulf of Oman. All naval and aerial assets in the region are utilized to allow safe passage for the carrier group through the Straits of Hormuz. Iran attempts to use swarm tactics with small surface boats, submarines, and UAVs to inflict heavy casualties.

Following the costly attack on U.S. ships and the continuing resolution of Iran to pursue weapons of mass destruction the President directs forces to commence a full-scale precision strike campaign against military anti-air and anti-surface missile installations, government and infrastructure targets in major cities, and all known nuclear program and ballistic missile sites.

3. Scenario 3 – Humanitarian Assistance

Summary: Following a disastrous typhoon in the Philippines and loss of government control, U.S. armed services provide humanitarian assistance and military peacekeeping to alleviate civilian crisis and heel anarchy.

Main reason to include scenario in analysis: As the largest national organization capable of overseas operations, the armed services have been, and will certainly be, called upon to assist other nations in times of natural disaster.

Possible scenario: An especially powerful typhoon strikes the Philippines, where nearly 100 million people live in an area of 116,000 square miles. Following the catastrophic storm food shortages grow worse in areas cut off from aid and the government loses control of the population. International military forces rush to aid the beleaguered nation. The missions of all forces are to conduct search and rescue, deliver humanitarian aid and enforce orderly behavior while government infrastructure is built up to resume control of all sovereign territory.

4. Scenario 4 – Full-Scale War

Summary: In order to battle domestic civil unrest, North Korea initiates aggression against the South, leading to a full-scale war between the United States and the communist dictatorship.

Main reason to include scenario in analysis: Full-scale war against a nuclear power must remain a core scenario in any analysis of U.S. armed forces needs in future military planning.

Possible scenario: The nuclear capable state of North Korea is highly volatile and has been in a carefully watched cease-fire with its neighbor to the south since the end of the Korean War. Tensions between the two countries are a cause for concern for the international community. The United States is significantly involved in ensuring the safety of the South Korean democracy.

Due to increasing civil unrest, North Korean dictator, Kim Jong-Un, externalizes blame for his nation's stagnant economy and instigates a conflict with South Korea over a shared industrial zone. In order to create *casus belli*, the dictator orders a North Korean ship to be sunk near the DMZ, laying the blame on South Korean aggression. The North Koreans then launch naval and aerial actions against South Korea. As military actions on both sides escalate, the United States is called upon to aid in the defense of its ally.

Armed forces mobilize on land bases and at sea for the coming struggle and are attacked by North Korean ballistic missiles and small submarines. Despite sustaining losses the United States continues to build up extreme military pressure against the government and military forces of the northern state. As North Korean leadership feels the end is near, weapons of mass destruction are used against American military targets in the Pacific and civilian South Korean targets. The U.S. continues to fight through the atrocities and finally manages to bring down the dictatorship.

B. SCENARIO SELECTION

1. Factor Rankings

As described above, the four scenarios identified are:

- 1) Anti-Access, Area Denial in South China Sea
- 2) Precision Strike in Iran
- 3) Humanitarian Assistance in the Philippines
- 4) Full-Scale War in North Korea

To determine the likelihood of a scenario happening, key factors were identified, ranked and evaluated to identify the highest risk scenario. Risk in this instance, refers to the scenario most likely to happen in the next 10–15 years (geo-politically and technologically) and poses the biggest threat to U.S. forces. The identification of the highest risk scenario allowed the team to concentrate focus and resources on a single scenario to evaluate the capabilities of the air wing and supporting force structure elements. The process flow is summarized in Figure 13.



Figure 13. Scenario selection process flow chart

Key Factors: The factors identified were based on stakeholders' inputs and analysis of threats and risks present in the existing environment. After much deliberation, three key factors were identified to describe the existing or future capabilities which will affect maritime forces. They are as follows:

- Mission Capabilities

A successful execution of mission is the key to accomplishing the goals of the scenarios. In this category, mission capabilities describe the key abilities that are required from the air wing to execute a successful mission. Key factors affecting mission capabilities are timeliness, communications, intelligence, readiness scalability and distribution. The definitions and descriptions of all factors are listed in Appendix A.

- Weapons/Warfare

Weapons/Warfare describes weapons required to support CSG mission execution. Key weapons identified are electronic and cyber warfare, anti-air, anti-missile, ballistic anti-missile, deep strike and mine warfare capabilities.

- Geopolitical

The geopolitical factors describe the political support, inter-governmental cooperation, and ease in access to ports location.

Summary of Scenario Rankings

Scenario and Factors Score	A2AD in South China Sea	Precision Strike in Iran	Humanitarian Assistance in Philippines	Full Scale War in North Korea
Mission Capability Factors	4.6	3.8	3.7	4.1
Weapons/Warfare Requirement Factors	3.3	3.6	1	3.5
Geo-Political Factors	3.8	3.3	4.2	4.5
Average Score	4.2	3.7	3	4
Overall Scenario Ranking	1	3	4	2

Table 1. Summary of scenario rankings.

The scenarios were then ranked, analyzed and evaluated. The scenario factor rankings confirmed that the A2AD scenario in the South China Sea presents a high risk and tests a wide spectrum of capabilities and functions of the U.S.'s future CVW force structure and CONOPS. Table 1. provides the high level analysis and ranking. More detailed analysis and rankings of these scenario factors can be found in Appendix A. With this method the team assessed the A2AD scenario is the most challenging situation in which many of the current and future capabilities of the U.S. military will be utilized.

C. BASELINE SCENARIO

The following baseline scenario was developed by the team and depicts what the Team believes to be a real-world unfolding of events that could take place in the South China Sea within the coming fifteen years. This baseline scenario describes the operational A2AD environment for which the future integrated CSG force structure and CONOPS should be able to adapt to in order to achieve mission effectiveness and reduce risk to the CVN. It should be noted that this scenario was detailed for the year 2029 so that the team could accurately acknowledge the pace of technological advance and more easily bound what could or could not be accomplished. Figure 14 illustrates a regional depiction of the South China Sea scenario.

2029 South China Sea Scenario:

Tensions over the Spratly Islands have reached a boiling point. The Joint Marine Seismic Undertaking (JMSU), a tripartite agreement between the Philippines, the PRC, and Vietnam, signed in 2004 to explore oil reserves in the Spratly Islands (almost exclusively within the Philippine's EEZ) ended in animosity between the three parties. In 2022, the governments of Brunei, the Philippines, Vietnam, and Malaysia published a multilateral statement of understanding delineating each country's claims to maritime oil and gas reserves within the Spratly island chain. The PRC vehemently protested the agreement, arguing that the JMSU agreement and China's subsequent role in the exploration of much of the area (conducted by China Oilfield Services LLC as part of the terms of the JMSU) granted them a sizeable stake in the reserves. The United States has remained cautiously neutral, stating only that this is a regional matter. A series of multilateral talks ensued, each of which broke down acrimoniously, as the PRC continued to insist on expanded claims within the Spratly Islands as well as demanding a portion of the revenue obtained by the ASEAN nations from the deposits. The last round of talks broke down after only two days of negotiations in 2028. The next day, the PRC deployed a carrier strike group claiming "routine training exercises within the PRC's EEZ." The strike group proceeded directly for the Spratly Islands, and conducted flight operations as well as gunnery and bombing practice against the appropriately named Mischief Reef. The Philippines lodged an immediate protest, claiming these operations were conducted well within the EEZ of the Philippines, and that they were a deliberate provocation aimed at the ASEAN nations' signatory to the resource sharing agreement. The PRC denied these claims, pointing to their historical ownership of Mischief Reef, with over 30 years of occupation by the PRC military and fishermen.

The United States expressed concern about the actions of the PRC, and moved to discuss the matter in a meeting of the UN Security Council. Discussion of the matter was promptly vetoed by the PRC, which claimed it was being antagonized by the United States, and reiterating that this was a regional matter that would be handled without involvement from the United Nations. Following a brief meeting, representatives from the ASEAN announced that increased security measures would be undertaken to ensure the security and prosperity of the Spratly Islands. Shortly thereafter, both the Philippines and Malaysia stepped up maritime patrols in the area, and satellite imagery revealed the presence of SA-17 air defense batteries in place on Vietnam-claimed Spratly Island (proper). In addition to the SAM batteries, space appeared to have been cleared for coastal defense cruise missile batteries and preparations for loading SS-N-26 Yakhont missiles was noted at Cam Ranh. These moves have enraged China, who sees the SS-N-26 batteries as a serious threat to its influence in the region. The PRC presented Vietnam with an ultimatum, stating in part

that it would view deployment of cruise missiles as an untenable challenge to the regional status quo, and that any attempt to do so would be met with force, if necessary. Vietnam asserted its right to defend it and its allies' territory and interests in the Spratly Islands, and the ship suspected to be carrying the SS-N-26 missile batteries set sail from Cam Ranh shortly thereafter.

Approximately 150nm from the coast, this ship was intercepted by a PRC Surface Action Group comprising one Type 52D DDG and two Type 54A FFGs. The ships hailed the Vietnamese-flagged transport and repeatedly instructed it to stop and prepare to be boarded for inspection to verify its cargo. The ship refused to comply, and proceeded on course. After over an hour of attempted communications, the Type 52D fired multiple shots across the bow of the transport ship. At this point the transport ship increased speed and began continuous transmissions of Mayday. Moments later, the Type 52D exploded violently, breaking in two just forward of the pilothouse, with only the stern section remaining afloat. Both Type 54A FFG began evasive maneuvers and activated their sonars. A helicopter was launched from one, and this began immediately dropping sonobuoys. The Vietnamese ship proceeded unimpeded for some time, but just as it was disappearing over the horizon a salvo of missiles was fired by one of the FFGs. Two ASCMs struck the Vietnamese ship, which exploded violently and disappeared beneath the waves with no survivors. A Philippine Navy Hamilton-class patrol ship was also fired upon as it approached the scene in response to the Mayday calls, and was struck by a single ASCM, killing 20 of its crew and leaving it adrift.

The Philippines, Vietnam, and the PRC now appear poised for war, with all countries placing their military forces on high alert. Malaysia and Brunei appear to be trying to deescalate the situation, although both have also increased the alert status of their militaries. The PRC is adamant that a Vietnamese submarine is responsible for the loss of its DDG, which Vietnam insists that no submarine was in the area and the explosion was caused by either a mechanical fault or sabotage onboard the Chinese vessel, also pointing out that the Chinese DDG was in the process of firing high-explosive ammunition at one of its ships in international waters in violation of the UNCLOS. An emergency session of the Congress of the Philippines was invoked shortly after the incidents, and an urgent request sent to the United States invoking the 1951 Mutual Defense Agreement. United States Pacific Fleet units have been placed on an alert status for immediate deployment to the South China Sea.



Figure 14. Regional depiction of the South China Sea scenario (after U.S. Energy Information Association 2013).

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V. FUNCTIONAL ANALYSIS

A. FUNCTIONAL DECOMPOSITION

The functional analysis phase of the systems engineering process allows individual component functions of a concept to be determined and then later developed further into the means to execute the functions in an operational environment. First, there needs to be a development of individual functions into a functional hierarchy describing what would need to be accomplished by the entire system of systems to make the solution concept valid. Using the current CVN capability structure as the baseline, the distributed force structure took that baseline capability and spread it out using multiple alternative concept ideas. This development made up a potential architecture framework and testable factors for the solution concept the Team termed, the Distributed Air Wing (DAW) – which is essentially a concept of concepts to be implemented to create an integrated Carrier Air Wing worthy of fighting in an A2AD environment.

As stated earlier, the South China Sea scenario was developed to help understand what possible functions would be essential to the operation of the DAW concept. From there, the functions were decomposed in a functional hierarchy necessary for friendly forces to counter A2AD threats. Assisting in the development of the DAW individual concepts was a functional analysis of an effective A2AD threat environment as described earlier. Understanding component functions of the A2AD environment allowed for an understanding of what critical A2AD functions needed to be countered by the DAW concept.

When the functional hierarchy for the DAW concept was developed, the functions were then implemented into the operational scenario to determine the functional flow. The functional flow block diagram (FFBD) shows how component functions are implemented in the scenario and determines if there are missing functions that need to be developed.

In addition to the functional decomposition and FFBDs, an N2 chart and IDEF0 diagrams were also developed. Using a variety of functional analysis tools allowed the Team to determine the capability gaps as well as what areas of the mission fell in and out

of the project scope. These tools also allowed for the utilization of different perspectives in determining the solution space for the force structure needed.

1. Functional Hierarchy and Flow Block Diagrams

One of the goals of the A2AD environment is to prevent U.S. forces from safely operating in the area of operation (AO). This would give an adversary the ability to conduct operations in a region that was favorable to its disposition. Starting with Level 0 Functionality, it was determined that the goal of the DAW concept would be to maintain regional stability. This would counter instability created by the A2AD environment by not collocating naval air forces in one location, for example the aircraft carrier, and would provide a possible kinetic force option to deter adversaries from unwanted actions. From there, determining factors for Level 0 needed to include a way for the DAW to maneuver into operating locations, provide similar mission capabilities to the CVN, be able to sustain forces, and having an ability to maintain flow of information in the battle space. Refer to Figure 15 and Figure 16. for the decomposition diagrams.

One of the Level 1 functions needed to complement the Level 0 function (**Maintain Regional Stability**) is to **Maneuver Assets**. The DAW concept of distributing force capabilities over a regional area, so as to not centralize a location for an attack, would require maneuvering assets as necessary to position them advantageously for defensive or offensive strikes. For example, the CVN is able to translate their forces anywhere on the globe at a moment's notice. If the CVN or any similar asset is included in the solution space for the DAW, it would need assets capable of maneuvering their force capabilities from the centralized location to other areas in the region, so that if one force is disabled through an attack, the total force capability would not be degraded or annihilated.

Once assets maneuver to essential locations, then those forces would need to be able to execute present-day mission-sets. There are many missions conducted by the CVN, but the most important missions that the team deemed essential for the CVW to conduct operations against A2AD threats would be Intelligence, Surveillance, and Reconnaissance (ISR); Strike, and Defensive/Offensive Counter-Air (DCA/OCA). These missions would need to be tailored for large-scale actions conducted against more

developed countries and for actions conducted in smaller scale conflicts. The tailoring of mission size to a particular size of conflict drove the idea to incorporate flexibility into the DAW concept.

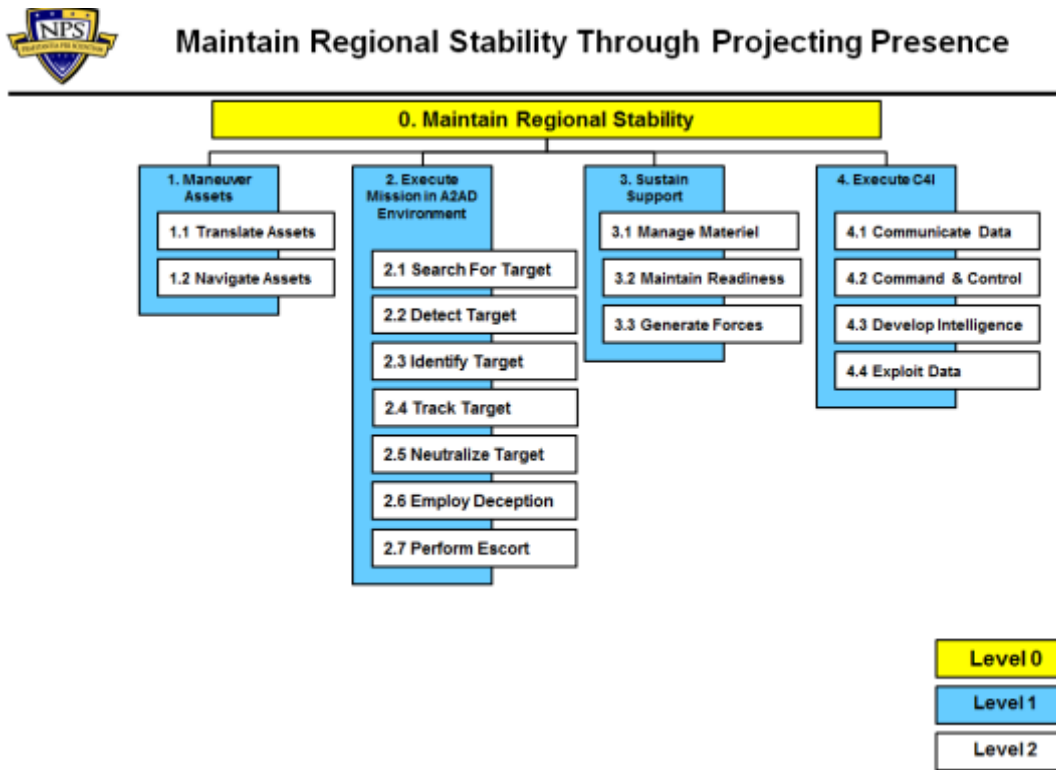


Figure 15. Maintain regional stability high-level functional decomposition.

The third function of the functional hierarchy concentrated on the ability of sustaining the support functions for the forces associated with the DAW concept. With more locations for air assets to operate from, there needs to be the creation of a secure logistical network to support DAW operations. One of the challenges with this function is that with dispersed forces, the network of logistical lines increases. This fact leads to more assets required to support the facilities required to implement the DAW. There will also need to be a function to make sure all personnel are trained and qualified to support the DAW concept which will represent the readiness of the operational force.

The last Level 1 function includes functions involved with C4I, which represents a complex function set that includes all functions of communicating, collecting, and

assessing information in the battle space. The flow of communications is essential in today's threat environment and there needs to be reliable C4I functions that allow for such flow.

As the Team decided that Logistics (part of **Sustain Support**) and Command and Control (part of **Execute C4I**) were out of the scope of this particular project, it was determined that the first two Level 1 functions (**Maneuver Assets**, and **Execute Mission in A2AD Environment**) were the most relevant to the project, and therefore the following Level 2 and 3 decompositions of these functions are presented in Figure 16.

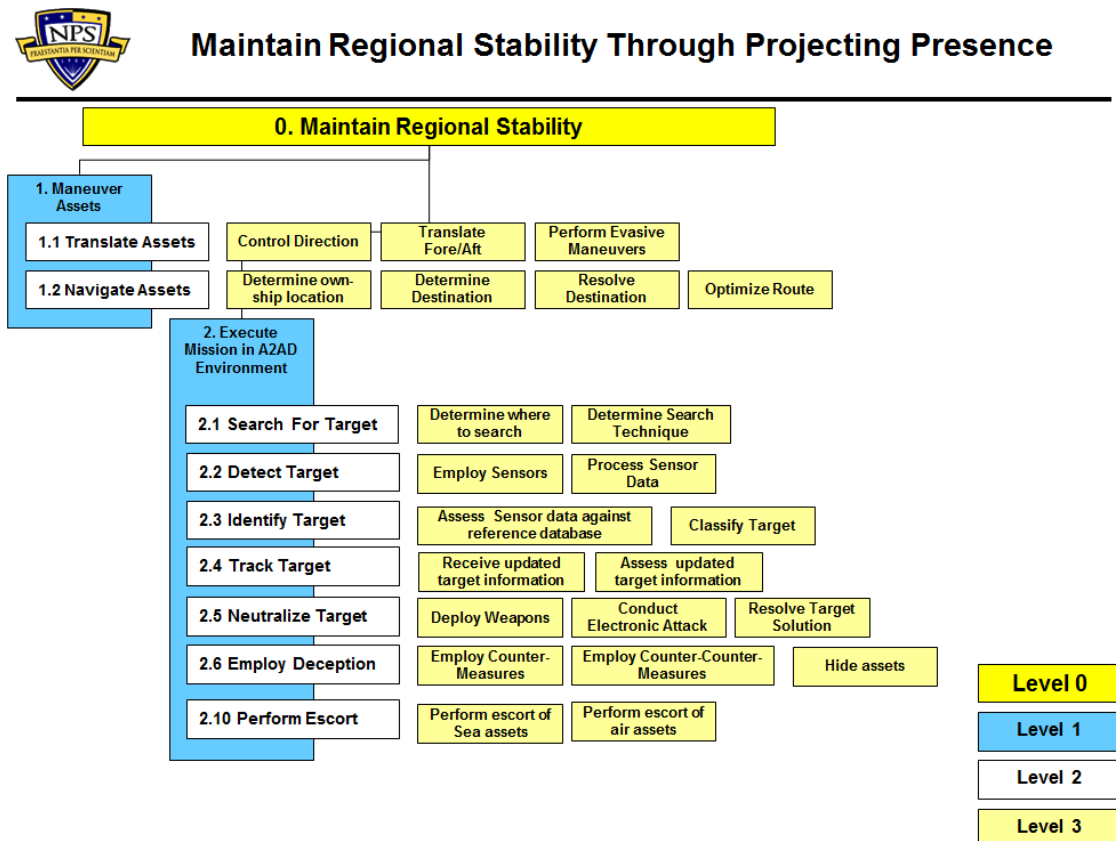


Figure 16. Maneuver Assets and Execute Mission in A2AD Environment Level 2 and 3 functions.

The following describes the functions and sub-functions in hierarchal format with the Functional Flow Block Diagram after the description of each Level 1 function.

1.0 Maneuver Assets: The CSG and integrating concepts must be able to maneuver assets. This function has two Level 2 functions: 1.1 **Translate Assets**, and 1.2 **Navigate Assets**. See Figure 17.

1.1 Translate Assets – This function provides the system with the ability to translate its deployed assets by controlling its direction, translating forward and backward and performing evasive maneuvers.

1.1.1 Control Direction – This function enables the system to control its direction as the system moves towards the targeted destination.

1.1.2 Translate Fore/Aft – This function provides the system with the capability to adjust its position by moving forward and backward to reach its commanded destination.

1.1.3 Perform Evasive Maneuvers – This function enables the system to perform evasive maneuvers to avoid oncoming hazards during a mission.

1.2 Navigate Assets – This function provides the system with the ability to maneuver its deployed assets to the correct locations. It will determine its current location and destination. With that, it will optimize the route and resolve the destination.

1.2.1 Determine own-ship location – This function provides the system with the capability to determine its current location before commencing on its new flight mission.

1.2.2 Determine Destination – This function provides the system with the capability to conclude the location of the destination based on the received mission command.

1.2.3 Resolve Destination – This function provides the system with the capability to ascertain the location of the destination based on the received mission command.

1.2.4 Optimize Route – This function enables the system to determine the most effective and efficient route that starts from its current location to its destination.

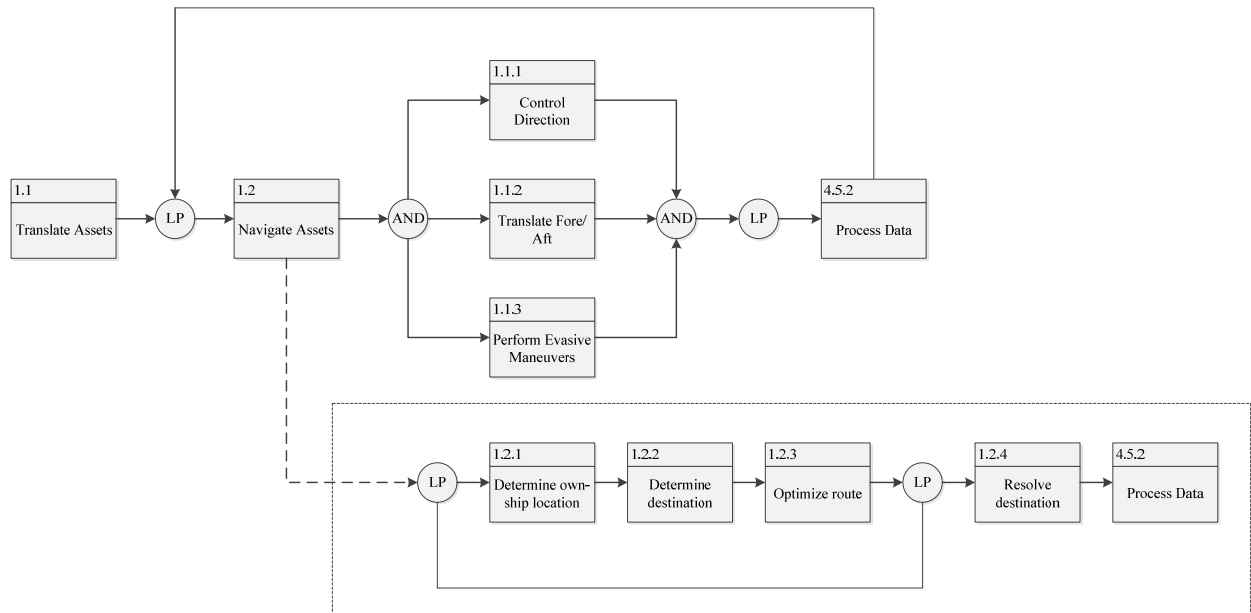


Figure 17. Translate assets (Function 1.1) FFBD.

2.0 Execute Mission in A2AD Environment: In order for the new CSG structure to be an operationally viable solution for the U.S. Navy, it will have to be able to conduct missions necessary to accomplish strategic goals within an environment that is beset with A2AD kinetic and electronic weaponry. It has seven level 2 functions to include: 2.1) **Search for Target**, 2.2) **Detect Target**, 2.3) **Identify Target**, 2.4) **Track target**, 2.5) **Neutralize Target**, 2.6) **Employ Deception** and 2.7) **Perform Escort**. Many missions have reiterative actions in order to continuously complete mission elements and are the reason many of the functions are looped. See Figure 18.

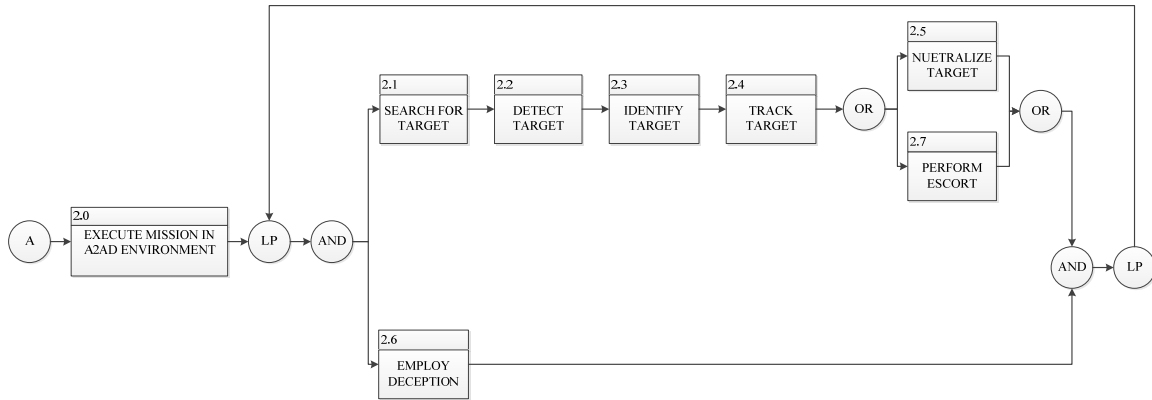


Figure 18. Execute Mission in A2AD Environment (Function 2.0) FFBD.

2.1 Search for Target- The new CSG structure will need to be able to adequately search for adversary targets in the various electromagnetic (EM) spectrums and in various domains within a region; the concentrated domains will utilize air assets to search for enemy assets operating in the sub-surface, surface, and air domain. Two level 3 sub-functions are: 2.1.1) **Determine Where to Search**, 2.1.2) **Determine how to search** and 2.1.3) **Determine what assets to use**. See Figure 19.

2.1.1 Determine Where to Search- Understanding the key locations to search for adversary assets is a priority for the CSG in order to protect itself against A2AD weapons, both kinetic and electronic. Measurable aspects of this function could consist of latitude and longitude coordinates developed from a variety of navigational assets.

2.1.2 Determine How to Search- Different regions and mission sets will require different search patterns and methods. Developing patterns consisting of linear or circular search methods with respect to a geographic point or with respect to the position of assets within the CSG structure, are methods of how (not limited to just linear or circular search patterns) search patterns could be

employed by the CSG. Measurable elements of this function are distances flown with respect to a geographic or other reference point.

2.1.3 Determine What Assets to use- There are many domains, such as the air and sea domain, to search for adversary targets and matching the proper search asset with the type of search that is to be conducted is crucial for operational success. For instance, the leadership within the CSG structure will need to know what methods of search assets are available and what EM spectrum that the search can be conducted in. Different spectrums have limitations and benefits for use. Measurable elements that need to be considered are range, endurance, and required sensor information needed.

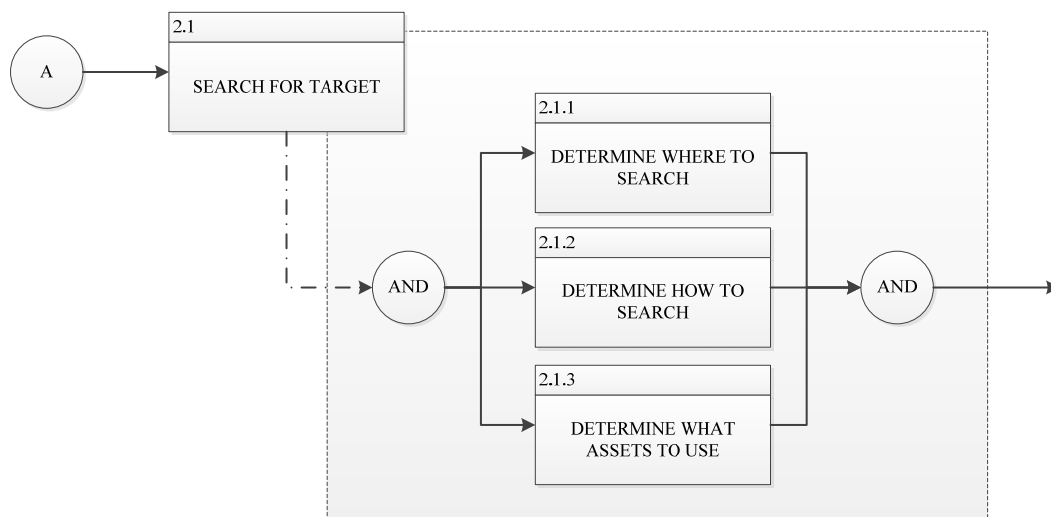


Figure 19. Search for Target (Function 2.1) FFBD.

2.2 Detect Target- The action of detecting a target of interest from background noise within a specific search region. This function is broken down into level 3 sub-functions including: **2.2.1) Employ Sensors** and **2.2.2) Process Sensor Data**. Measurable elements of this function could be the number of found targets with a specific time period. See Figure 20.

2.2.1 Employ Sensors- Includes the activation and operation of the specific sensor or sensors aboard a search asset. It can be measured by rate of information gathered and coverage area.

2.2.2 Process Sensor Data- This function is the act of converting received data the data into discernable information for the user. This function can be measured by whether or not targets can be found.

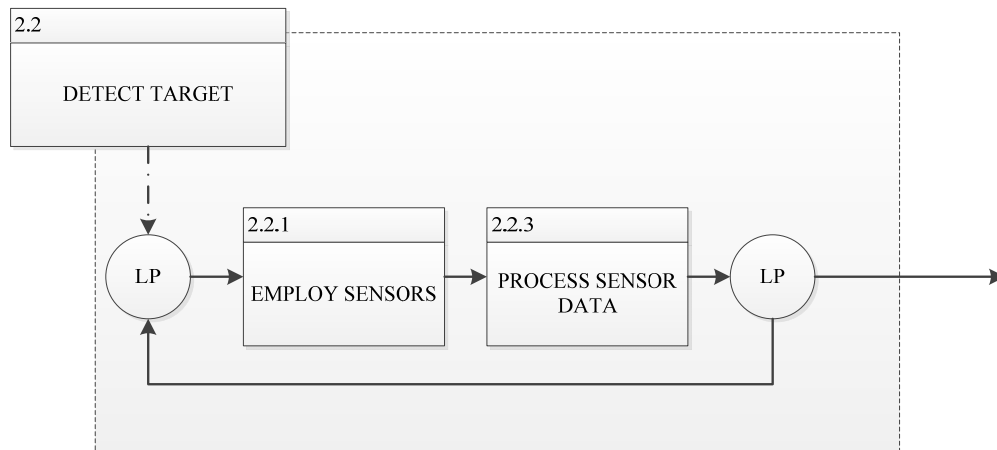


Figure 20. Detect Target (Function 2.2) FFBD.

2.3 Identify Target- Is the function of interpreting the process data from the computing source and identifying it for the CSG. See Figure 21.

2.3.1 Assess Sensor Data against Reference Database- Is the function of comparing the received data against a known database of threats in the adversary's arsenal. This database should be continuously updated. This can be measured by indicating whether or not the data can be assessed.

2.3.2 Classify Target- Is the function that classifies what the received data most likely is. The probability of classifying the target correctly is a measurable element of this function.

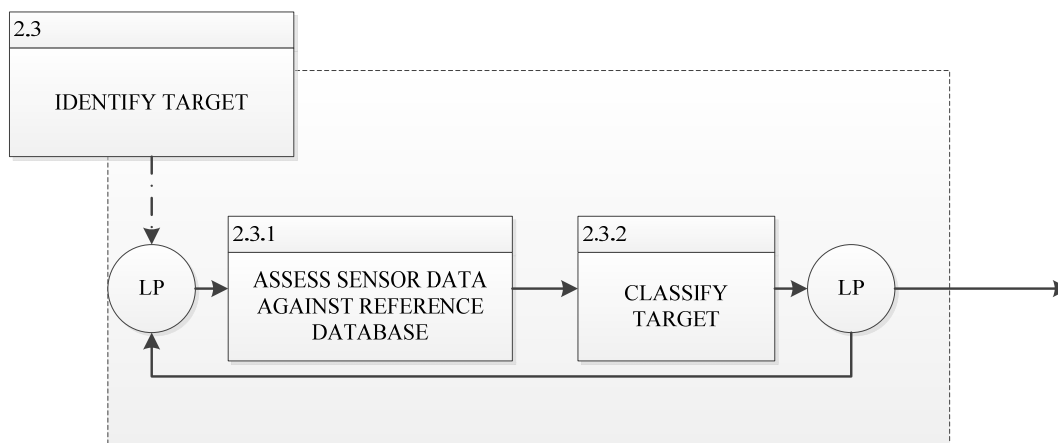


Figure 21. Identify Target (Function 2.3) FFBD

2.4 Track Target- This is the process of continuously monitoring the target and its actions in the region if the decision is made to do so. It is broken down into two level 3 sub-functions: 2.4.1) **Receive Updated Target Information** and 2.4.2) **Assess updated target information**. See Figure 22.

2.4.1 Receive Updated Target Information- Includes the reception of target information such as position, heading, speed, and other operational aspects. Data flow is a measurable element to this function.

2.4.2 Assess Updated Target Information- Is the function of interpreting what the identified target is doing and if it is a threat to the CSG.

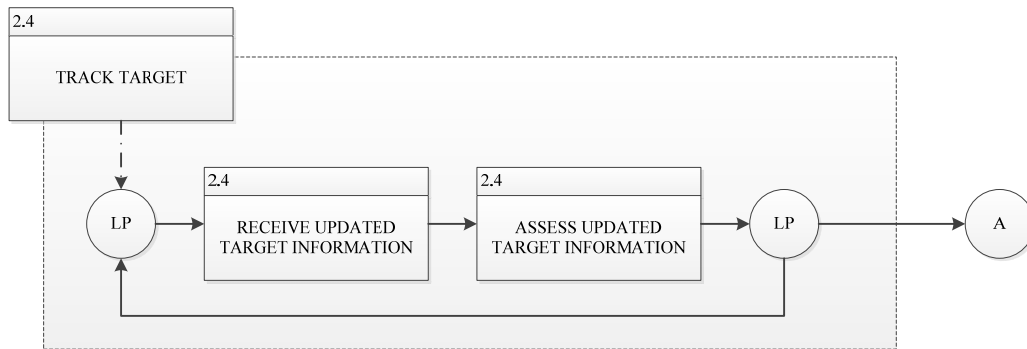


Figure 22. Track Target (Function 2.4) FFBD

2.5 Neutralize Target- Is that act of using force to disrupt or take down an adversary target. It has three level 3 sub-functions to include: **2.5.1) Deploy Weapons**, **2.5.2) Conduct Electronic Attack** and **2.5.3) Resolve Target Solution**. See Figure 23.

2.5.1 Deploy weapons- Includes the release of kinetic weapons at a target classified as an enemy. It can be measured by how many kinetic weapons can be delivered in a unit of time.

2.5.2 Conduct Electronic Attack- Is the function of disrupting EM signals utilized by the enemy asset in order to prevent use of that asset or to eventually take-down the asset. It can be measured by the amount of power generated and amount of signal degradation produced.

2.5.3 Resolve Target Solution- Is the function of determining if the target has been effectively neutralized and if not, the process will be looped until the target is neutralized. It can be measured by probability of whether or not the target was neutralized effectively (probability of kill).

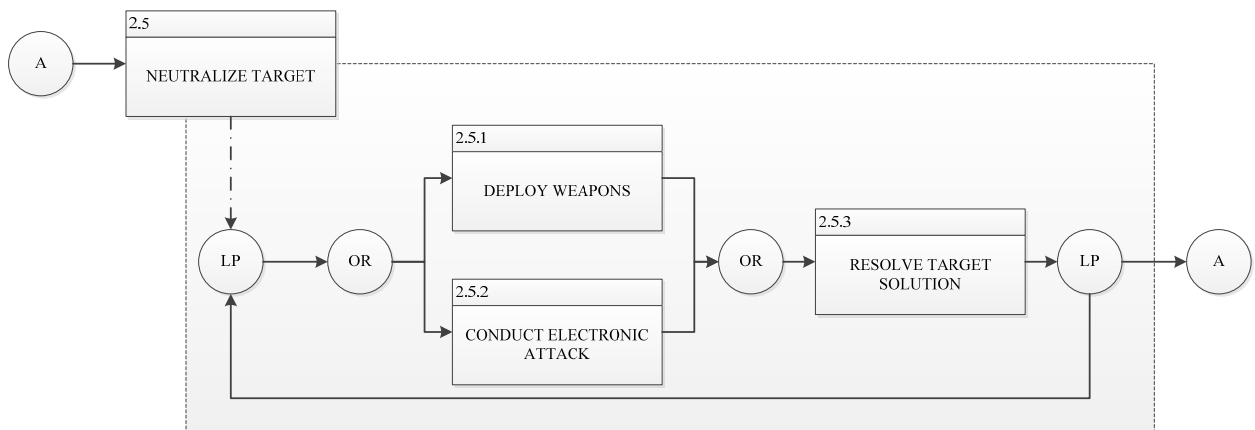


Figure 23. Neutralize Target (Function 2.5) FFBD

2.6 Employ Deception- Is the act of deploying deceptive means as defensive strategy for the CSG to confuse the adversary in order to gain the initiative. It is broken into three Level 3 sub-functions including: 2.6.1) **Employ Counter-Measures**, 2.6.2) **Employ Counter-Counter-Measures** and 2.6.3) **Hide Assets**. See Figure 24.

2.6.1 Employ Counter-Measures- Includes employing assets to counter adversary threats and to target a specific enemy kill-chain action. It can be measured through the times employed versus the amount of successful times friendly assets evaded an enemy threat.

2.6.2 Employ Counter-Counter-Measures- Includes employing assets to counter an enemy threat that has a defensive capability against a non-redundant counter-measure. It can be measured through the times employed versus the amount of successful times friendly assets evaded an enemy threat with the initial counter-measure defeating capability.

2.6.3 Hide Assets - Includes actively employing techniques to mask the signature of friendly assets. Rate of detection by adversary is a way that this can be measured.

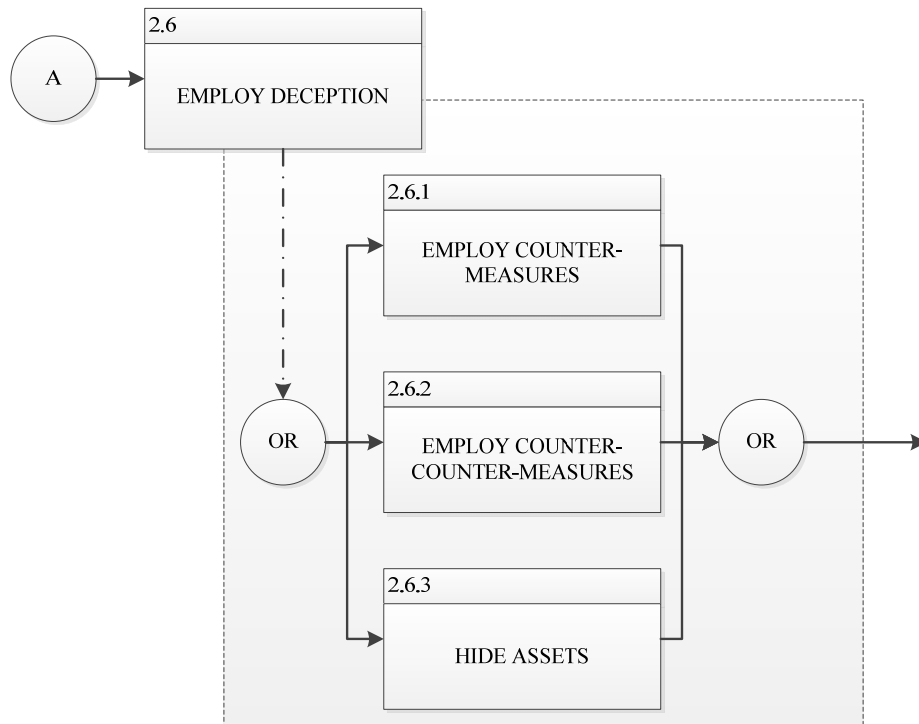


Figure 24. Employ Deception (Function 2.6) FFBD.

2.7 Perform Escort- Is the action of utilizing one set of friendly assets to travel with and protect another set of friendly assets from any enemy action. It is broken down into two level 3 sub-functions which are: 2.7.1) **Perform Escort of Sea Assets** and 2.7.2) **Perform Escort of Air Assets**. Both sub-functions can be down in conjunction with one another, which is why the “and” is included in the sub-function. See Figure 25.

2.7.1 Perform Escort of Sea Assets- Is the action of protecting friendly sea-surface assets. It can be measured by the number of times friendly sea-surface assets depart and arrive at an objective destination.

2.7.2 Perform Escort of Air Assets- Is the action of protecting friendly air assets. It can be measured by the number of times friendly air assets depart and arrive at an objective destination.

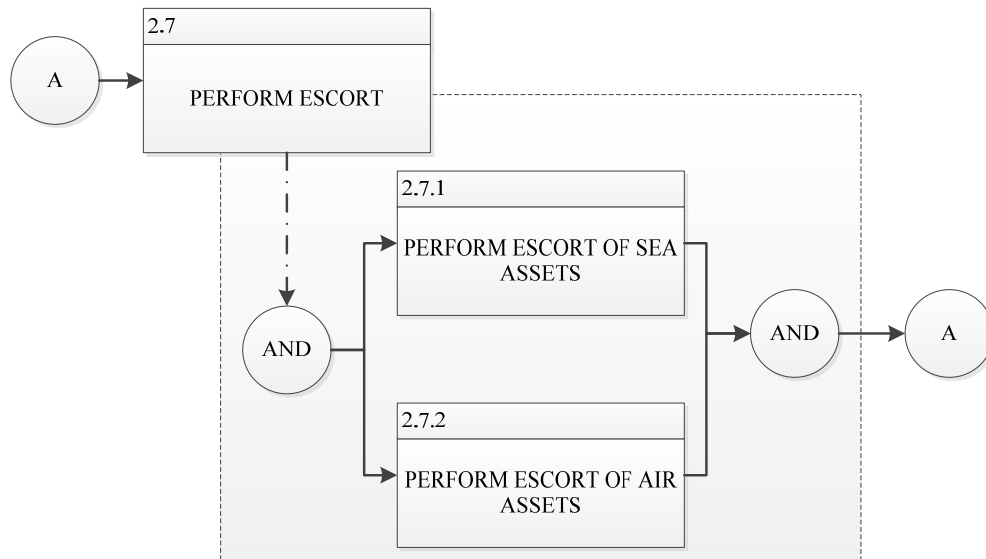


Figure 25. Perform Escort (Function 2.7) FFBD.

3.0 Sustain Support - This function provides the system with the ability to sustain operations behind the initial deployment. This function consists of three sub-functions that are performed concurrently: **3.1) Manage Materiel, 3.2) Maintain Readiness and 3.3) Generate Forces.** See Figure 26.

When a CVW is deployed, initial supply is usually inadequate to sustain the entire campaign operations. Hence, it is important to have a robust resupply support system to perform sustained operations and these functions allow the CVW to receive external resupplies, reinforces and maintain its own personnel and assets, and to project its force into battle.

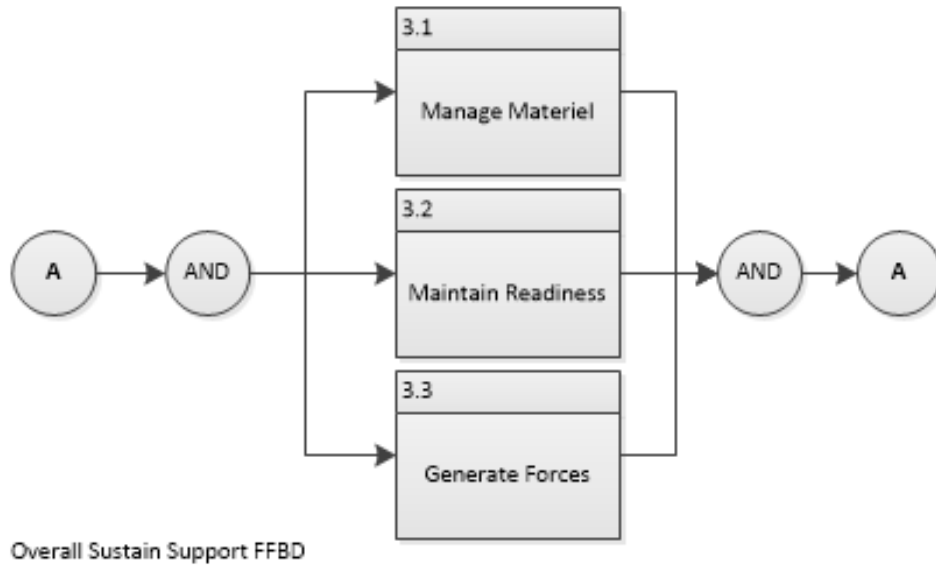


Figure 26. Sustain Support (Function 3.0) FFBD.

3.1 Manage Materiel – This function provides the system with the ability to receive, manage and allocate supplies and essentials for the conduct of operations. See Figure 27.

3.1.1 Receive Materiel – This function enables the system to receive external resupplies. This function includes interfacing with resupply assets to load and unload supplies.

3.1.2 Administer Materiel – This function allocates supplies and essentials from storage facilities to the receiving assets for operational use.

3.1.3 Manage Inventory – This function provides the system with the capability to store supplies, track supplies movement and process resupply requests.

3.1.4 Transport Materiel – This function enables the system to transport materiel between inventories and resupply assets.

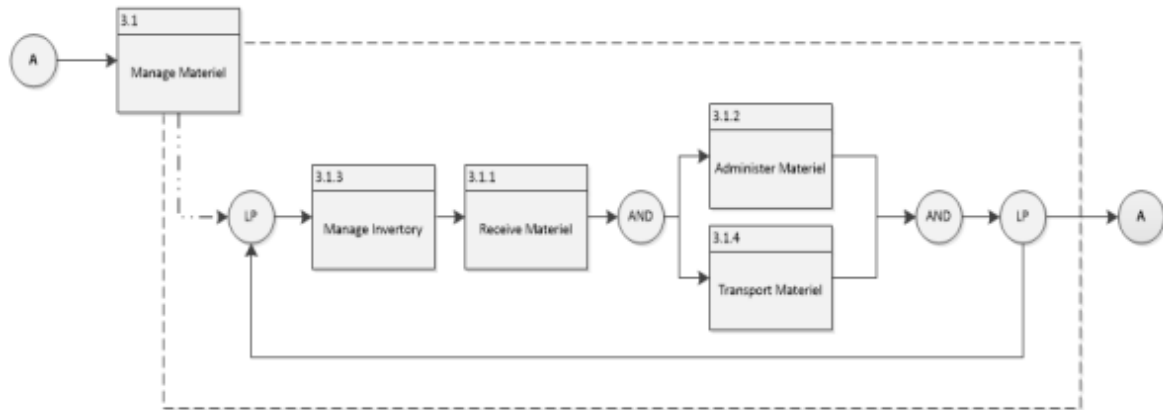


Figure 27. Manage Materiel (Function 3.1) FFBD.

3.2 Maintain Readiness – This function allows the system to maintain the preparedness of the system to meet the operational requirements. See Figure 28.

3.2.1 Maintain Personnel – This function supports the system to provide maintenance of physical and mental well-being of personnel for operational and non-operational situations.

3.2.2 Maintain Proficiency – This function allows the system to train and maintain personnel’s proficiency in equipment and operational scenario handling.

3.2.3 Maintain Assets – This function provides the system with the capability to maintain and repair assets to maintain their serviceability level.

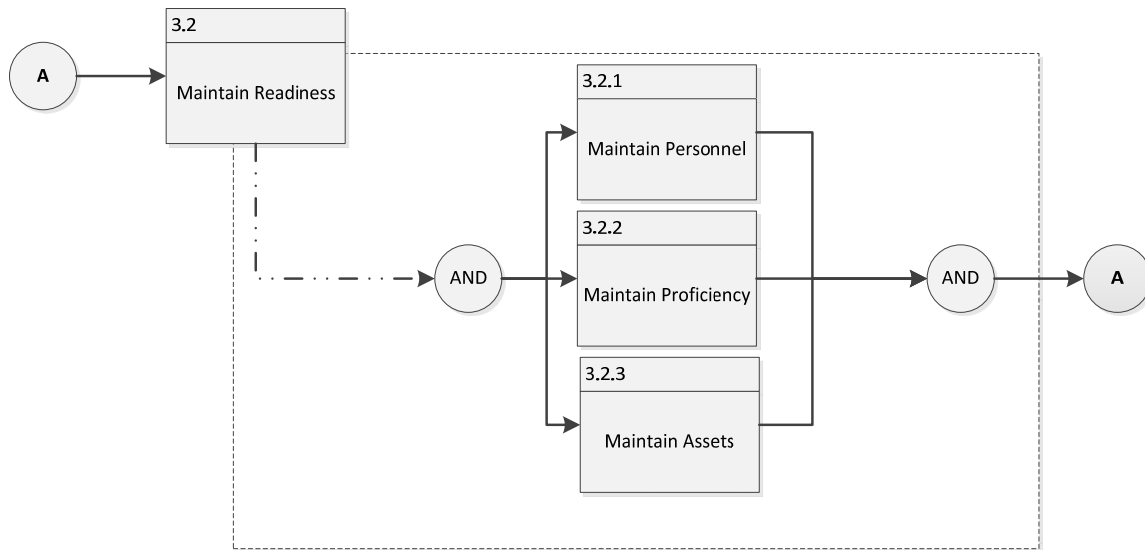


Figure 28. Maintain Readiness (Function 3.2) FFBD.

It is critical that the CVW is always well prepared to perform any designated missions. Thus, it is imperative to provide the operating crew with basic essentials like food and water, as well as hygienic facilities and amenities for personnel maintenance (3.2.1). On top of which, the personnel must be proficient in operating the CVW assets and executing battle tactics in order to maximize operational effectiveness. Hence, frequent training (3.2.2) is vital to maintain this proficiency. Also, frequent preventative and corrective maintenance of assets (3.2.3) is fundamental in achieving high serviceability and availability of assets to be called upon for mission execution.

3.3 Generate Forces – This function allows the system to project assets and generate sorties for operations. See Figure 29.

3.3.1 Launch Assets – This function provides the system with the ability to launch assets into the air in accordance to flight regulations and procedures.

3.3.2 Turnaround Assets – This function supports the system to provide swift resupplies and battle damage assessment and repair to assets during missions.

3.3.3 Recover Assets – This function supports the system to recover assets during operations by performing asset landing preparations.

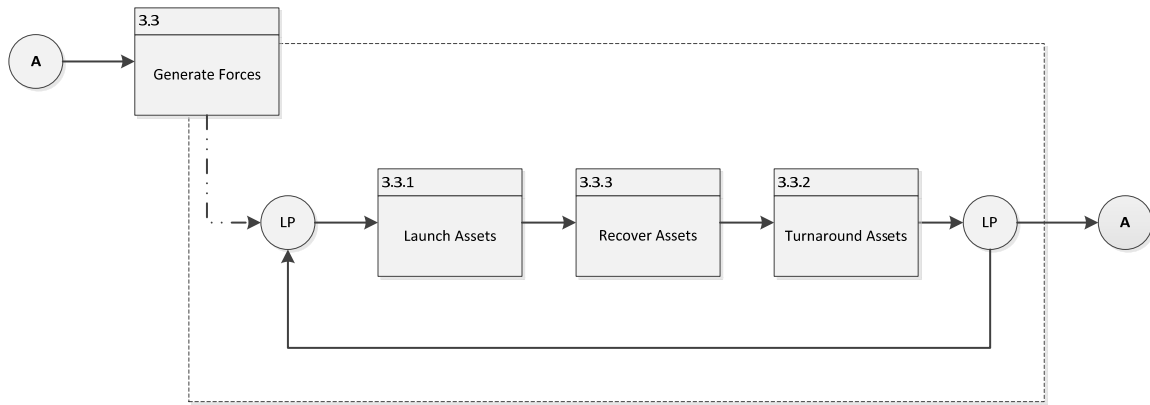


Figure 29. Generate forces (Function 3.3) FFBD.

It is vital for CVW to sustain presence and mission effectiveness over the adversaries through constant sortie generation for missions. With Function 3.3 **Generate Forces**, it allows the system to **Launch** (3.3.1), **Recover** (3.3.3) and **turnaround assets** (3.3.2) through refuel, re-arm and repair efficiently and swiftly for maximized combat effectiveness.

4.0 Execute Command, Control, Communications, Computers and Intelligence

(C4I) - The Execute C4I function will be a looping function that is prevalent in all other functions. The Execute C4I function begins with the **Communicate Data** (4.1) function that **Receives Data** (4.1.5) and the system proceeds to **Exploit the Data** (4.4) or use it to **Develop Intelligence** (4.3). This processed information is then used to support the **Command and Control** (4.2) function. The output from the **Command and Control** function is a mission order that is then communicated through the **Communicate Data** function to the appropriate elements within the Future Naval Strike Group or other agencies. See Figure 30.

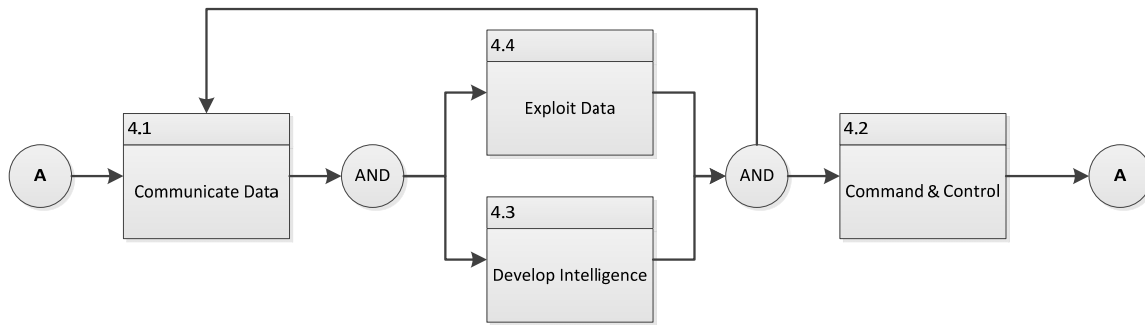


Figure 30. Execute C4I (Function 4.1) FFBD.

4.1 Communicate Data – This function provides the system with the ability to exchange information.

4.1.1 Transmit Information – This function enables the system to transmit information either autonomously or when commanded to do so. The function will also enable the system to transmit information of various formats, including, but not limited to, text and imagery.

4.1.2 Interoperate with Friendly Forces – This function enables the system communicate with friendly and allied forces and provides the capability for the system to exchange information with these forces.

4.1.3 Monitor Frequencies – This function provides the system with the capabilities to continuously scan any specified frequency band for transmissions, both to it and between external systems.

4.1.4 Manage Frequencies – This function enables the system to communicate over a range of frequencies. This provides flexibility in communications and also enables interoperability of the system with other external systems that may operate in a specific frequency.

4.1.5 Receive Information – This function enables the system to receive information transmission either autonomously or when commanded to do so. The function will also enable the system to

receive information of various formats, including, but not limited to, text and imagery.

Communicate Data has the following sub-functions. Within the **Communicate Data** (4.1) function, the interoperability of the communication system is enabled by the **Interoperate with Friendly Forces** (4.1.2) function. Friendly forces include both U.S. and allied forces. The communication system will **Manage and Monitor Frequencies** (4.1.3 and 4.1.4) simultaneously. Depending on the operations, it then **Transmit or Receives Information** on a specific frequency (4.1.1 and 4.1.5) before reverting back to frequency management and monitoring functions. See Figure 31. Note: In this figure the it should be interpreted that the functions can of **Manage and Monitor Frequencies** (4.1.3 and 4.1.4) can be done simultaneously with **Transmit or Receives Information** (4.1.1 and 4.1.5) – denoted by the “AND” between the figures; while the “OR” represents that an entity is either **Transmitting “or” Receiving Information**.

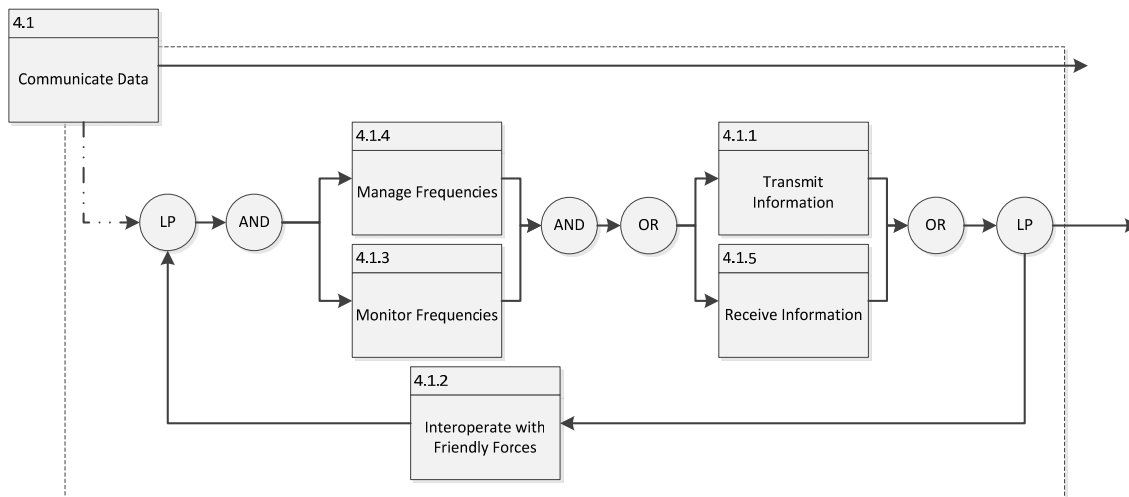


Figure 31. Communicate Data (Function 4.1) FFBD.

4.2 Command & Control – This function provides the system with the necessary capabilities to exercise Command and execute Control. See Figure 32.

4.2.1 Establish Situational Awareness – This function enables the system to build an overall air/sea/land picture from various sources

of inputs and intelligence with the objective of providing the operator with the information and intelligence required for decision-making.

4.2.2 Plan Mission – This function provides the system with the capability to assist and enable the development and formulation of strategies and concepts for operations.

4.2.3 Determine Mission – This function enables the system to assist the operator to resolve the type and scope of the operation to be executed.

4.2.4 Disseminate Orders – This function enables the system to relay Commander’s decisions, direction and guidance to the distributed forces across and beyond the operational network.

4.2.5 Assign Assets – This function provides the system with the capability to support the identification and assignment of assets, by the Commanders and Planners, for the purpose of mission execution.

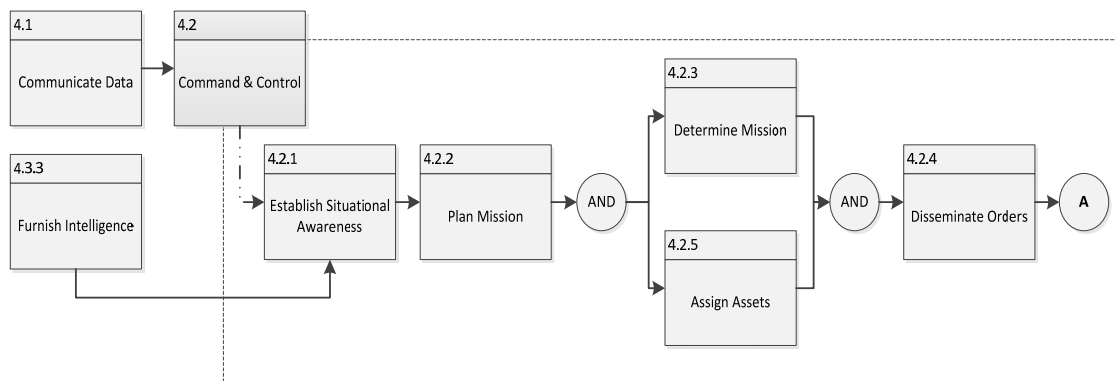


Figure 32. Command and Control (Function 4.2) FFBD.

Command and Control has the following sub-functions (4.2). The Situational Awareness will be established (4.2.1) using Information from the **Communicate Data** and **Furnish Intelligence** (4.1.3) functions. With the situational awareness established, **Mission Planning** (4.2.2) is performed. With the mission planned, the **Mission**

Determination (4.2.3) and **Asset Assignment** (4.2.5) is performed simultaneously. Finally, the generated **Mission Order is Disseminated** (4.2.4) through the **Communicate Data** function to the respective elements.

4.3 Develop Intelligence – This function provides the system with the capability to process data it receives from the various ISR sources and use the data to generate intelligence so as to establish SA, aid decision-making and operations planning. See Figure 33.

4.3.1 Receive Intelligence – This function provides the system with the capability to receive intelligence in text, image, video and any format to be specified.

4.3.2 Process Intelligence – This function provides the system with the capability to perform pre- and post-processing of received intelligence to enable the management of such received intelligence.

4.3.3 Furnish Intelligence – This function provides the system with the capability to transmit intelligence, in either its original format or an otherwise specified format to another entity in the same network.

4.3.4 Store Intelligence – This function provides the system with the capability to retain in its database all received and processed intelligence and provide the operator with the ability to retrieve such intelligence as desired.

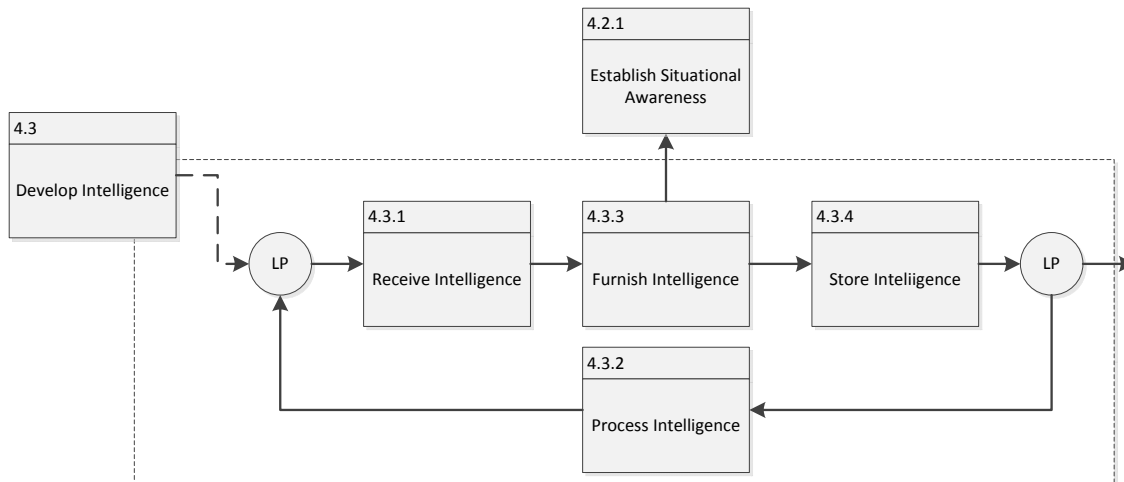


Figure 33. Develop Intelligence (Function 4.3) FFBD.

Development of Intelligence has the following sub-functions (4.3). **Intelligence is Received** (4.3.1) and **Processed** (4.3.2). It is then **Furnished** (4.3.3) on-demand to enable the **Establishment of Situational Awareness**. All Intelligence are **Stored** (4.3.4) for future retrieval whenever necessary.

4.4 Exploit Data – This function enables the system to process the data it receives or prior to transmission. The function enables the system to compress or decompress, encrypt or de-encrypt such data or extract specific information from such data that it may require for the performance of other functions. Exploitation of Data (4.4) has the following sub-functions **Data Received** (4.4.1) is **Processed** (4.4.2) to **Decrypt** (4.4.4) it. The decrypted data is then either Stored (4.4.3) or **Displayed** (4.4.6). **Data Transfer** (4.4.5) is also achieved through the **Communicate Data** function mentioned earlier. See Figure 34.

4.4.1 Receive Data – This function enables the system to receive data transmitted from other systems within the network. The function will also enable the system to receive data of various formats, including, but not limited to, text, image and video.

4.4.2 Process Data – This function enables the system to process the data it receives or prior to transmission. The function enables the

system to compress or decompress, encrypt or de-encrypt such data or extract specific information from such data that it may require for the performance of other functions.

4.4.3 Store Data – This function enables the system to write data in either permanent or transient format, with the capability to retrieve such stored data at a later time.

4.4.4 Decrypt / Encrypt Data – This function enables the system to decrypt / encrypt data received or prior to transmission.

4.4.5 Transfer Data – This function enables the system to transmit data between its own-ship subsystems.

4.4.6 Display Data – This function provides the system with the capability to present any requested data in a specified format on a display system.

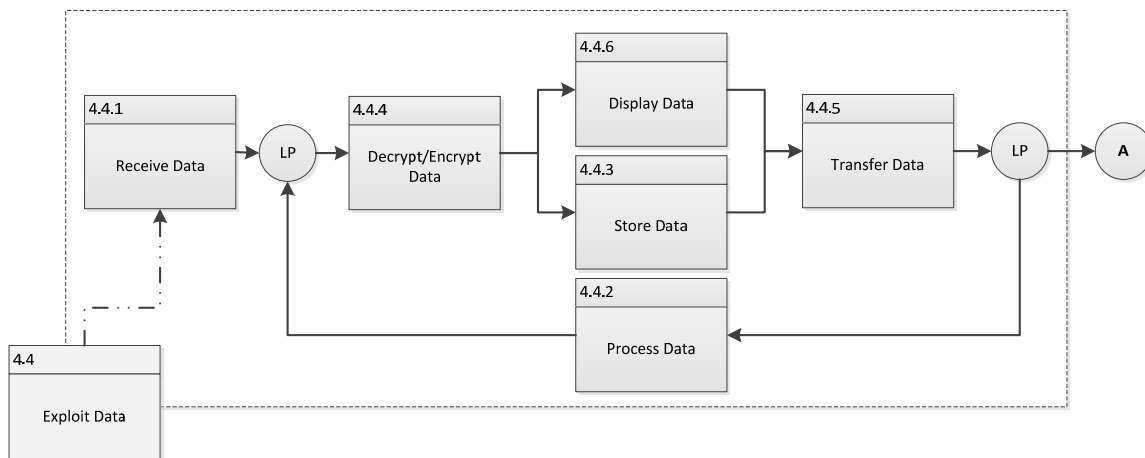


Figure 34. Exploit Data (Function 4.4) FFBD.

B. N2 DIAGRAM

The N2 Diagram is a tool used to show the input-output relationships between the different functions of the system. As the Level-1 functional decomposition contains aggregation of high-level tasks, the Level-2 functions were used to show the major interactions. Figure 35 depicts the N2 Diagram for the Level-2 functions.

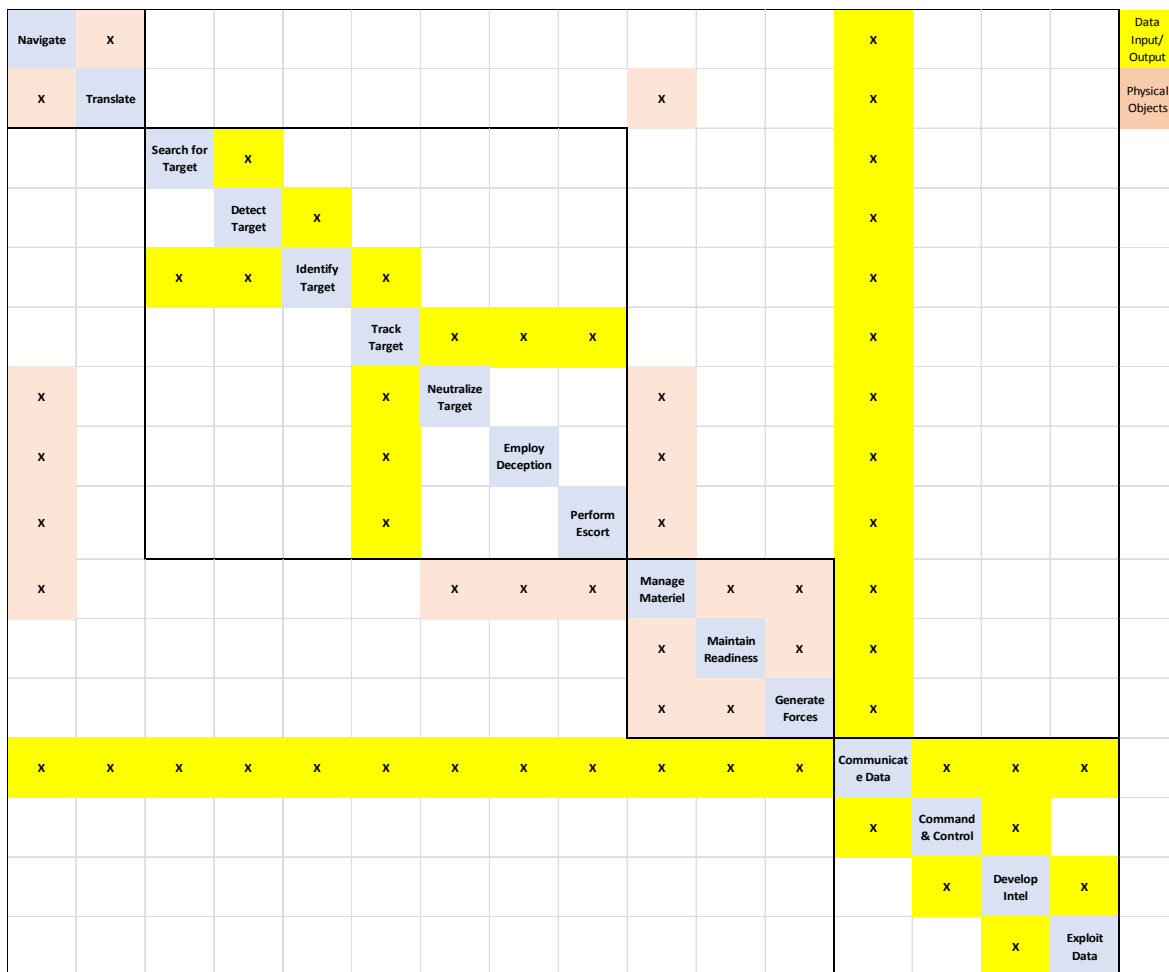


Figure 35. N2 Diagram.

High-level analyses of the dependencies between the functions are described below.

The navigation block of the N2 diagram comprises **Translate Assets** and **Navigate Assets**. **Translate Assets** together with **Navigate Assets** function forms a group, in that navigation of assets typically involves movement of assets from one location to another, i.e., **Translation of Asset**. The output of the **Translate Assets** function causes a change in the location of assets, the location data (i.e., blue-force tracking information) is feed to **Command & Control** functions to provide a common situation picture.

The mission block of the N2 diagram comprises of the various functions that are needed in the process of executing a mission. **Search, Detect and Identification of Target** is grouped together due to the common theme of these functions.

Part of this function involves sensory functions that comprises of **Search for Target**, which provide the guidance to the **Detect Target** function. The **Detect Target** feed track information from sensors to **Identify Target** for target classification and classified tracks are then passed over to the **Track Target** function. The target tracks from the **Identify Target** are fed back to **Search for Target** to provide data to guide the search process. The output from these functions includes detection information that can be used for **Tracking of Targets** or fed as data for **Develop Intelligence**.

The functions for **Tracking of Target** generates track-information (i.e., target vectors) that may be used to generate firing solutions to **Neutralize Targets** or to provide the **Employ Deception** functions to counter hostile targets targeted at the force. In network-centric warfare, the track-information may also be shared to other entities within the system through the **Communicate Data** functions.

Other than outright offensive and defensive operations, the system may also need to perform other support functions such as **Perform Escort**. During **Neutralize Targets, Employ Deception and Perform Escort**, the system is likely to want to continue to **Track Target** until the operation is over, i.e., target is destroyed or incoming threats is no longer present. **Perform Escort** would also involve some form of movement of the ships and/or air wing, i.e., these would need to navigate to different locations to perform their task.

To support the operations, it is necessary for the system to be able to provide the necessary logistic and maintenance resources for the operations. This is the purpose of the Maintenance block, which comprises functions **Manage Materiel, Maintain Readiness and Generate Forces**. The **Generate Forces** function refers to the sustenance of a force, i.e., manpower, equipment that can be deployed in time of needs. The **Maintain Readiness** functions would include maintaining proper assets in time of needs and proficiency in the various command and non-combat operations, i.e., in C4I, ISR, Attack and defense operations. The **Manage Materiel** function includes the planning and

tracking of assets, inventories and equipment. Hence, any operation that would consume resources, i.e., **Neutralize Target, Deploy Deception, Perform Escort, Translate Assets**, would affect and be affected by the function of **Manage Materiel**.

These three functions are interconnected, that is in order to **Maintain Readiness** there is a need to maintain a certain level of supplies for use. **Manage Materiel** is also important during non-mission time for the purpose of providing sufficient materiel for training needs, which is needed to **Generate Force**. Likewise, to maintain readiness, it may be necessary to consume materiel, which would need to be factored in and managed through the **Manage Materiel** function. Operations to **Manage Materiel** would all involve some form of movement of the ships/air wing, i.e., these would need to transport materiel to/from supply bases, etc.

The Command and Control block comprises of function such as **Communicate Data, Command & Control, Develop Intelligence** and **Exploit Data**. The **Communicate Data** function forms the backbone of the information flow for the system in that any part of the sub-system would need to obtain information for its operation, e.g., the **Navigate** function would need to know the location that it is to navigate to, or what target is assigned to a sub-system for its **Neutralize Target** function, or the movement and inventory level for **Managing Materiel**. Likewise, position of assets and sensory information are also fed using the **Communicate Data** function to the **Command & Control** function to develop the situation picture.

All the data that are gathered through the **Communicate Data** function are passed to the **Command & Control, Develop Intelligence** and **Exploit Data** function for planning and processing to generate information that may be used during operations.

Intelligence data from the **Develop Intelligence** would be used by the **Command & Control** to provide situation data. The current mission plan from the **Command & Control** function may be used as inputs for **Develop Intelligence**. Intelligence data would be used by the **Exploit Data** functions to persist, stored or processed. Processed data from the **Exploit Data** may in-turn be used by **Develop Intelligence** to additional information for the situation picture, i.e., intelligence information from generated by the

Develop Intelligence may be feed into the **Command & Control** to update its situation picture.

C. IDEF0 FUNCTIONAL MODELING

Integrated Definition for Functional Modeling (IDEF0) is a process-oriented modeling tool that is popular in industry, especially in the military and government sectors. It shows how information flows while displaying the input-output relationships throughout a system.

Most importantly, the IDEF0 is able to communicate all of the model decisions and activities that take place within the system. Understanding the inputs, outputs, decisions and activities is important when conducting a thorough functional analysis of how a system operates or how it should be designed to operate. This is why the team selected this tool to perform a functional analysis on the DAW concept. The diagram in Figure 36 illustrates the basis of IDEF0 (Blanchard and Fabrycky 2011).

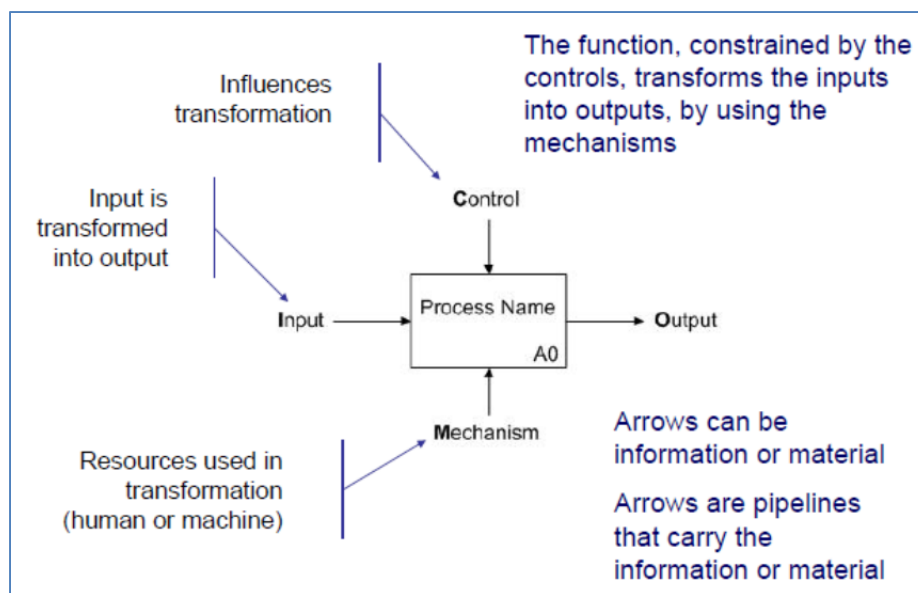


Figure 36. Inputs, Controls, Outputs and Mechanisms definitions.

After functional decomposition, Levels 0 and 1 were imported into this tool and their various Inputs, Controls, Outputs and Mechanisms (ICOMs) were identified. Figure 37 shows the various ICOMs for Level 0. In order to maintain regional stability, the team

noted that several major Controls such as Asset Specifications, Location Proximity and Resource Availability are required. In total, 10 controls were identified. Together with these controls there are three significant inputs and four resources while four outputs were generated from level 0.

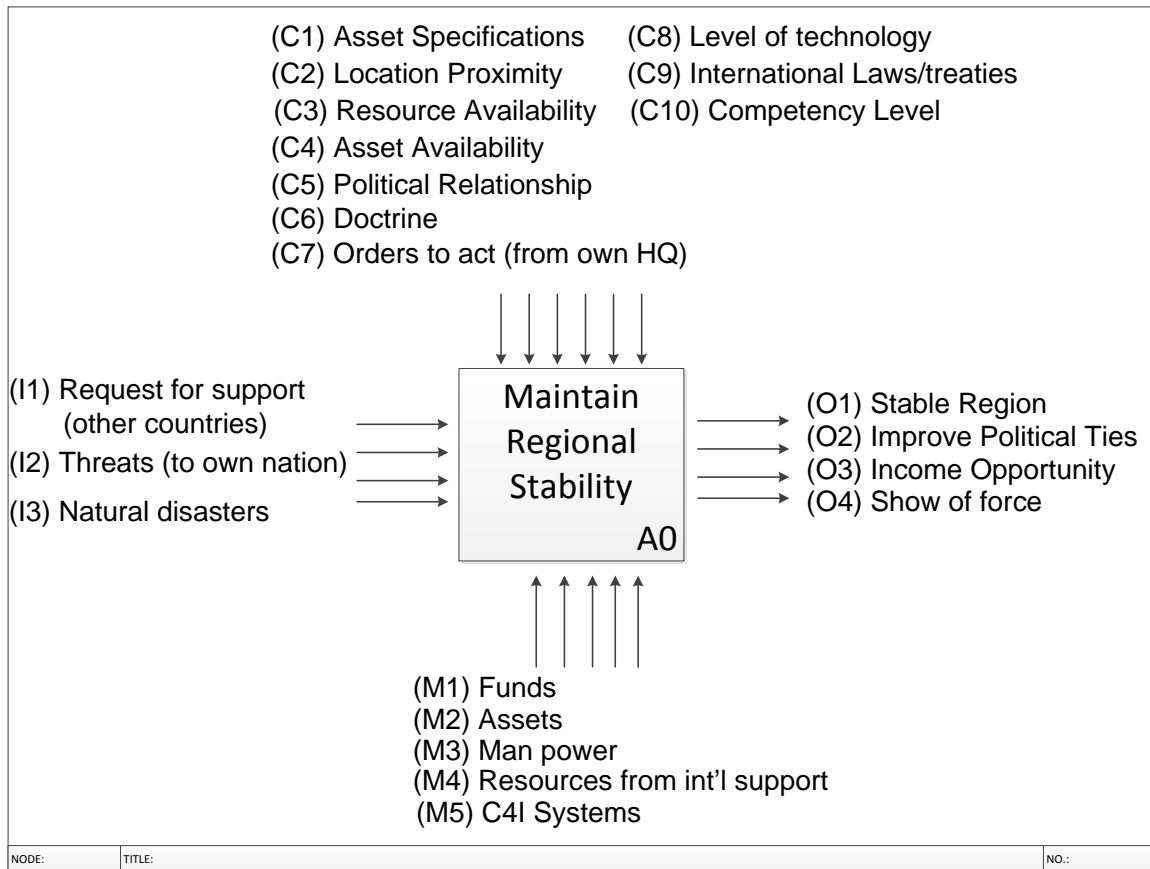


Figure 37. IDEF0 - Level 0 for Maintain Regional Stability.

After Level 0, the team examined the next level of the IDEF0 model. At Level 1, there are four main functions: **Maneuver Assets**, **Execute Mission in A2AD Environment**, and **Sustain Operations**, and **Execute C4I**.

As this model depends on the Functional Hierarchy, any changes will propagate downwards to the IDEF0 model. As mentioned previously, the team has undergone several rounds of discussion during functional decomposition and several drafts were produced.

The ICOM for the various functions were identified after active brainstorming. After several intensive rounds of evaluation and discussion, the IDEF0 model illustrated in Figure 38 for Level 1 was developed.

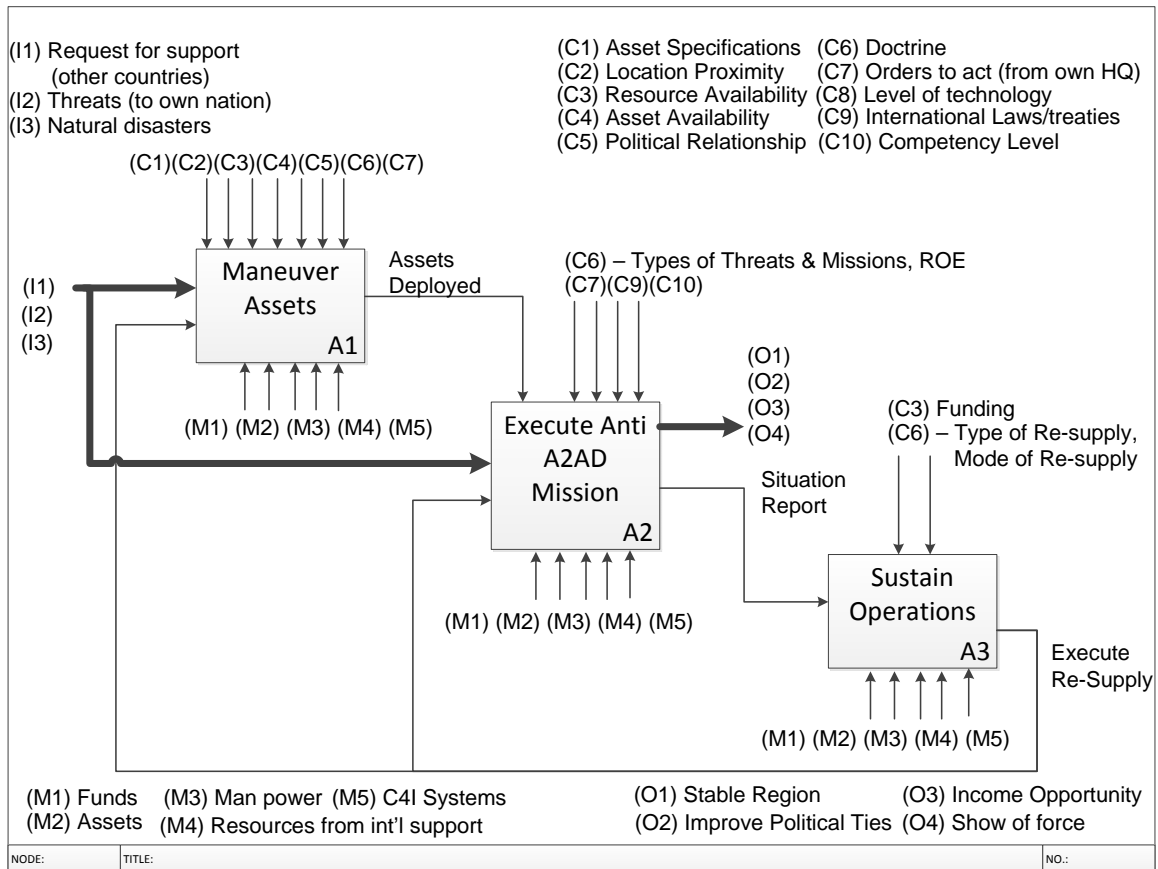


Figure 38. IDEF0 - Level 1.

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VI. REQUIREMENTS DEVELOPMENT

A. HIGH LEVEL REQUIREMENTS

The following is a list of high-level requirements based on the gaps identified for the current CVW. To address the risks of threats that can potentially disable a CVN and its associated air wing in an A2AD environment, three key requirements for the proposed solution are:

1. The system shall be capable of operating in an A2AD environment
2. The system shall help to reduce risk to the operation and human life
3. The system shall maintain sufficient mission capabilities

For these requirements to be measurable, i.e., to be able to be verified, they are further refined into more specific level requirements. The following are the refined requirements for requirement (1), i.e., to be able to operate in an A2AD environment. Possible A2AD environment includes the threat of ballistic missiles capable of disabling the CVN and potential communication jamming within the environment. Hence, the sub-requirements to be able to operate within such an environment include:

- 1.1 The system shall be capable of operating in a region with high EM interference
- 1.2 The system shall be protected against single point of failure (e.g., loss of mission capability due to loss of CVN)

The following are the refined requirements for requirement (2), i.e., the system shall help to reduce risk to the operation and human life.

- 2.1 The system, as a whole, shall be capable of defending against attacks
- 2.2 The system shall reduce the loss of human life

One identified risk of the CVW is that the CVN is a high-value target. Damage to the flight deck can disable the CVN's ability to effectively launch missions. Holistically, this vulnerability may be addressed by either dispersing the assets or protecting the critical assets.

To reduce risk to human life, the solution should, as a whole, be able to defend attacks with equal survivability, i.e., dispersing of forces may weaken the amount of protection available for the units; however, this should not mean that the system becomes more vulnerable. Hence, any proposed solution that aims to disperse the forces should also consider how such dispersion could prevent itself from becoming vulnerable.

The following are the refined requirements for requirement (3), i.e., to maintain sufficient mission capabilities:

- 3.1 The system shall have sufficient strike capabilities.
- 3.2 The system shall have sufficient ISR capabilities.
- 3.3 The system shall have sufficient counter-air capabilities.

As there is a likelihood that further forces may employ small unit size or dispersed forces, the overall solution should still provide sufficient mission capability through the synergy of the various components of the solution.

B. OBJECTIVES, MEASURES OF EFFECTIVENESS, MEASURES OF PERFORMANCE

Interviews conducted with the respective stakeholders enabled the team to identify two key objectives for the future naval air wing. The objectives are:

Achieve favorable war termination

Minimize BLUE FORCE losses

The team explored a spectrum of Measures of Effectiveness (MOE) based on the two objectives. The discussions and resulting iterations in determining the MOEs enabled the team to crystallize the thinking for the DAW and clarify any misconceptions about what the future naval air wing should or should not be. Ultimately, this effort helped to define the form and function of the future naval air wing's force structure.

Table 2 summarizes the Objectives, MOEs and Measures of Performances for the future naval air wing.

Objective 1	Achieve Favorable War Termination		
MOE	Strike Power	Defensive/Offensive Counter Air	ISR Power
MOP	Asset Availability, Mission Success Rate, Sortie Generation Rate, Weapons Payload, On-station Time, Relative Combat Power, Percentage Target Destroyed		
Objective 2	Minimize BLUE FORCE Losses		
MOE	Combat Attrition		
MOP	Loss-Exchange-Ration (LER), Engagement Range, Probability (Kill Hit)		

Table 2. Objectives, MOEs and MOPs.

1. Objective 1: Achieve favorable war termination

a. Measures of Effectiveness

This objective exposes the need for the future naval air wing to provide the U.S. Navy with the capability to bring about a swift and decisive conclusion to any armed conflict in an A2AD environment. The future naval air wing shall provide the USN with an appropriate level of capabilities while providing improved operational flexibility for the Combatant Commanders.

To enable a focused approach to the effort, the team identified three critical missions that should be organic to the future naval air wing. These missions are Strike, Defensive and Offensive Counter Air (DCA and OCA), and Intelligence, Surveillance and Reconnaissance (ISR). These three missions will guide the development of the MOEs and consequently the lower-level requirements.

The team found that there was no single MOE that adequately and elegantly elucidated what the future naval air wing should be to realize the objectives. To this end, the team developed unique composite MOEs that endeavor to articulate the capability-measure that the future naval air wing should meet.

For the first objective of achieving a favorable war termination, three composite MOEs were developed, with their respective definitions:

Strike Power

Defensive/Offensive Counter-Air Power

ISR Power

(1) Strike Power:

Strike Power = Assets x Payload x Mission Success Rate x Sortie Generation Rate
--

This MOE measures how hard, how fast, and how well we can throw a “punch.” The “how hard” is measured by the number of assets and the weapons payload. The “how fast” is measured by the sortie generation rate. The “how well” is measured by the mission success rate. Of interest is how many weapons can successfully be brought to bear on targets in a given amount of time.

(2) Defensive/Offensive Counter-Air Power

Defensive/Offensive Counter Air Power = Assets x Relative Combat Power x On-Station Time x Mission Success Rate x Sortie Generation Rate

This MOE measures how hard, how fast and how well the future air wing can fight back from an air-to-air perspective. While it is derived largely from a defensive viewpoint, this measure can also be applied for Offensive Counter Air. The use of Relative Combat Power (RCP) (Bahram 1995) in this MOE underscores the need for the future naval air wing to possess a commensurate or better combat capability than the current carrier air wing.

(3) ISR Power

ISR Power = Assets x On-Station Time x Mission Success Rate x Sortie Generation Rate

This MOE measures how far and wide, how well, and how long the future air wing can generate and maintain situational awareness, and develop intelligence.

b. Measures of Performance

The Measures of Performance (MOP) that are identified for this first objective “Achieve favorable war termination” are:

(1) Asset Availability

The percentage of assets that is available at any given time. Only assets that are combat-capable are to be considered available for tasking. Assets under scheduled and corrective maintenance are excluded.

(2) Mission Success Rate

The percentage of tasking that is successfully carried out by the tasked assets. A success mission is one where the tasked asset has accomplished all tasked mission objectives.

(3) Sortie Generation Rate

The number of sorties that a platform can generate for a particular type of asset.

(4) Weapons Payload

The absolute weapons payload that an asset can carry into combat.

(5) On-station time

The time that an asset can remain within the area of operations or area of interest. It neither includes ingress and egress time, nor time for aerial refueling and navigation.

(6) Relative Combat Power

Combat power is a cumulative of the combat capability of a particular asset, to include its maneuverability, firepower, protection, and leadership, the dynamics of combat power, in combat against the adversary. When compared against another asset, the Relative Combat Power is derived. A RCP of 1.0 means that both assets are identical in the combat capabilities that each brings to into combat.

(7) Percentage Target Destroyed

The percentage of assigned targets that are destroyed after each mission.

2. Objective 2: Minimize BLUE FORCE losses

a. Measures of Effectiveness

This objective expresses the need for the future naval air wing to enable the reduction to a minimum, the expected losses that BLUE FORCE will suffer in the event of an armed encounter in an A2AD environment. The future naval air wing shall allow the Combatant Commanders to have greater flexibility in decision-making and shall be more survivable against A2AD threats.

For the objective of minimizing BLUE FORCE losses, it is determined that a single MOE encapsulated the desired capability and performance of the future naval air wing. The MOE is Combat Attrition.

(1) Combat Attrition

Combat attrition measures the rate at which a side sustains losses to its personnel or materiel. The future naval air wing should be strive to be more survivable in an A2AD environment, and thus should result in an overall lower combat attrition for the BLUE FORCE.

b. Measures of Performance

The Measures of Performance (MOP) that are identified for this second objective “Minimize BLUE FORCE losses” are:

(1) Loss-Exchange Ratio

Loss exchange ratio is a figure of merit in attrition warfare. It is usually relevant to a condition or state of war where one side depletes the resources of another through attrition. This MOP measures the number of RED FORCE kills for every BLUE FORCE loss.

(2) Engagement Range

Engagement range measures the distance at which a shot can be fired against an adversary. The intent is to have a “First Look, First Shot, First Kill” capability against any adversary in an A2AD environment.

(3) Probability (Kill | Hit)

The probability that an asset will be killed given that it was hit. This is the vulnerability of the asset.

VII. DAW SOLUTION PART 1: THE DISPERSED AIR WING CONCEPT

A. THE DISPERSED AIR WING OPERATIONS CONCEPT

To improve the survivability of the Distributed Air Wing concept, one potential solution is the Dispersed Air Wing. This concept takes the current or near-future Carrier Air Wing and/or components of USMC Air Combat Elements and disperses them throughout small air bases in allied countries. This solution reduces risk by eliminating the possibility that the entire CVW is put out of action as a result of one missile strike against the carrier. Dispersing the aircraft also greatly increases the adversary's targeting requirements and the number of missiles required to achieve the same effects. In the context of the South China Sea scenario, the prime locations for dispersed basing are the Philippines, especially Palawan Island; Northern Malaysian Borneo; and Vietnam.

1. Concept Description and CONOPS

To determine the requirements, advantages, and challenges of such basing, it is important that the concept be described fully. The dispersed air wing would operate out of three fundamental base types, outlined below.

a. Dispersed Hubs

Hubs constitute the largest and most capable of the base types used in the dispersed air wing concept, in the form of regional airports that are temporarily repurposed to act as air bases, logistics hubs, and maintenance for Carrier Air Wing aircraft. The CVN itself is considered a hub under such a construct. As the physically largest of the three base types, they also are likely the most vulnerable, so additional defensive measures may be considered, to include SAM emplacements, BMD measures such as AEGIS ship stationing or Patriot battery deployment, and hardening and shelters to protect aircraft, ordinance, and fuel from attack (Stillion and Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks* 1999). As illustrative examples in the context of the South China Sea scenario, there are several

obvious choices for hub bases. In the Philippines, potential bases include, but are not limited to:

- San Jose Airport, Mindoro
- Francisco Reyes Airport, Coron
- Puerto Princessa Airport, Palawan

b. Tactical Strike Bases

The Tactical Strike Base (TSB) is a more limited base than the hub. Its primary airstrip, as envisioned, is likely no more than a straight stretch of highway, with limited ramp space provided for approximately one squadron of aircraft (10-15 at most bases), along with around 300–400 support personnel and pilots. Logistics and maintenance support is also considerably more limited than at a hub. Each designated base is provided with limited hardening and stores to support wartime operations.

The advantage of such basing lies in the more dispersed nature of such basing. Adversary targeting would be complicated by the requirement to determine where such basing exists, and whether or not aircraft are currently utilizing it. This minimizes the disadvantage of limited defensive measures being provided for each base. Finding and identifying potentially suitable areas for the installation of such basing would include cooperation with host nations, perhaps to the extent of providing funding for the construction of the bases under the guise of developmental aid. Further, host nation air forces could be trained to rapidly disperse to the basing in the event of conflict, bolstering their ability to withstand attack and defend their airspace in the event of an overwhelming attack.

c. Expeditionary Air Bases

The smallest and most limited of the three base types, the Expeditionary Air Base (EAB) is simply rapidly cleared areas from which U.S. or allied forces could disperse and operate STOVL aircraft such as the F-35B (NWDC 2013). These bases would, at most, host a full MEU Air Combat Element of aircraft, typically six aircraft, along with roughly 100 support personnel and pilots. These bases would be selected based on their relative

isolation, but with support roads in place to provide logistics. Later in the report, an EAB location optimization problem is explored in minimize the risk to such bases.

Finally, these bases would provide further advantage in the realm of counter-targeting, as their dispersed nature and relative isolation would make it difficult to locate them. This feature could further be enhanced through the use of camouflage techniques and strict emissions control while operational. With few aircraft and personnel assigned, hardening and defensive coverage would be reduced or eliminated altogether. Additional analyses of EAB susceptibility to satellite targeting and vulnerability to ballistic missiles are described later in the report.

2. Advantages and Challenges

The advantages to the Dispersed Air Wing concept primarily lay in the difficulty the concept poses to the adversary in terms of targeting. Compared to a single aircraft carrier, a collection of geographically disparate smaller bases, especially if there is confusion as to which ones are operational, makes for a far more difficult targeting problem. A further advantage lies in the relationship building with host nations that can result as the concept is advanced. Working with host nation air forces and cooperating in the construction of bases will pay dividends in the event that conflict breaks out. Not only will it reinforce the United States' image as a force for good in the region, it will provide tangible benefits to the armed forces of the host nation as well as to U.S. forces operating from the bases or in the region. If potential bases are identified in advance, dispersion can take place rapidly, helping to reduce risk to force and counter the area denial threat.

A further advantage lies in the flexibility provided by such a basing construct. Not only can these bases be used in time of outright conflict, they can be used leading up to a potential conflict to act as a deterrent. The host nation, or the U.S., actively dispersing its air forces throughout the region would provide a powerful message to a potential adversary as tensions rise. Simply exercising such ability would provide valuable messaging as well, and could deter conflict if adversaries are unsure of their ability to decisively defeat the U.S. and their allied air forces in order to gain aerial supremacy during conflict.

Simultaneously, the Dispersed Air Wing concept has a number of drawbacks. First and foremost, the dispersed nature of the basing would significantly increase the difficulty of providing prompt and sustained logistics support in time of conflict. This can be partially mitigated through identifying potential bases in advance and pre-staging vital equipment, fuel, and ordnance in the host nation prior to the outbreak of conflict, but sustained combat would provide a significant logistical challenge.

Additionally, Dispersed Air Wing basing is vulnerable to political pressure. During wargaming, several Red teams attempted to apply political pressure on nations hosting Dispersed Air Bases with mixed results. Such measures, if successful, would undermine the ability for the U.S. to project power into certain regions. To mitigate this, strong partnerships must be forged with nations where the United States intends to utilize such a construct.

Another disadvantage lies in the vulnerability of such bases to attack. While larger bases will have defensive capabilities and hardening measures, they are not as well defended as a carrier at sea, and lack a significant defensive advantage the carrier possesses: mobility. This limited defense can be partially offset by employing measures such as camouflage and emissions control, but vulnerability to things such as HUMINT or satellite imaging is harder to counter.

B. EXPEDITIONARY AIR BASE (EAB) PROTECTION ANALYSIS

1. Background

The philosophy of protecting a small, dynamic asset like an expeditionary air base is different than the protection philosophy of a CVN. For a small sized EAB, defense relies mostly on avoiding enemy detection and reducing risk given a hit. An EAB will not have active defense systems, which could reduce the likelihood of being hit given detection.

Reducing the likelihood of enemy detection is accomplished by having a small footprint for an EAB. The EABs should rely on as many pre-located assets as possible, so that the change to the surroundings is not immediately apparent to the non-local

population or from satellite imagery. Probability of detection is further reduced by frequent redeployments of the EABs based on the expected time to detect by the enemy.

Reducing damage inflicted by an incoming missile strike (conditioned on detection) must be accomplished without significantly increasing the footprint. For that reason damage reduction relies mostly on separating the main assets by a sufficient distance so that no incoming missile may damage more than a single asset.

This section focuses on modeling the expected damage to an EAB's main assets if a missile strike was launched against it.

2. Exact Model: Upper-Bound for the Probability of an Incoming Salvo Destroying at Least Two Aircraft

a. Model Description

In the worst case, it can be imagined that the enemy will be able to specifically target every aircraft in its designated parking location and fire a salvo when all aircraft are present. This implies that the planes can be parked far enough apart so that shots at any one aircraft do not affect any other aircraft. In that case the probability of a missile hitting an aircraft is determined by the distribution of the miss distances. If the miss distance is smaller than the lethal radius of the warhead, the aircraft is destroyed. A Raleigh Distribution (Kress and Washburn 2009) was assumed for the miss distances with parameter equal to the standard deviation of circular normal miss distance of the missiles. For this model it is assumed a salvo of 12 missiles is launched against an EAB with two missiles aimed at every aircraft. The standard deviation of incoming missiles is assumed to be 100 meters. An illustration of the model may be seen in Figure 39.

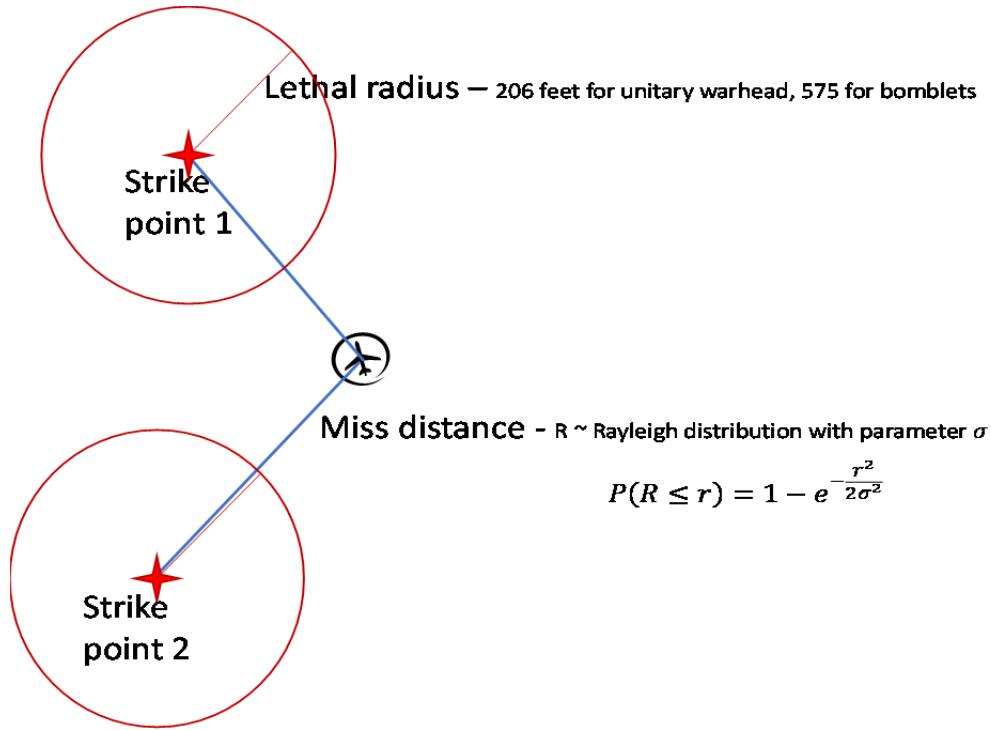


Figure 39. Lethal radius and miss distance diagram.

The probability of a missile to hit closer than the lethal radius, destroying the aircraft is

$$p_{\text{missile hitting}} = 1 - e^{-\frac{R_{\text{lethal}}^2}{2\sigma^2}}$$

where R_{lethal} is the lethal radius of the incoming warhead and σ is the standard deviation of the miss distance of the missile.

The lethal radius is decided according to the type of warhead. In this model we take into account two types of warheads: a unitary warhead with a lethal radius of 206 ft. and a warhead equipped with dispersible bomblets with a total lethal radius of 575 ft. (Stillion and Orletsky 1999).

The model shows that the probability of an aircraft to be hit is the following

$$p_{\text{A/C hit}} = 1 - p_{\text{both missiles hitting}} = 1 - p_{\text{missile hitting}}^2$$

The total number of aircraft hit is Binomial with 6 trials, 1 for each A/C in the EAB and the probability found previously:

$$\#_{A/C \text{ hit}} \sim \text{Binomial}(6, p_{A/C \text{ hit}})$$

The chance of at least two aircraft being destroyed is given by the following

$$p_{\text{at least 2 A/C destroyed}} = 1 - \text{CDF}_{\text{binomial}}(6, p_{A/C \text{ hit}})$$

b. Results

Design	Spacing	Warhead	Prob. Of 30% destruction with salvo of 12 missiles
Single	>200 m	Unitary	62%
Single	>300 m	bomblets	>99%

Table 3. Upper bound results for Probability of 30% destruction with 12 missiles.

These results give an upper bound for the actual probability of destruction with a salvo of 12 missiles. These results show that if the enemy is able to target individual aircraft using a missile with a miss distance significantly smaller than the lethal radius, the enemy may be very effective in aircraft destruction on the EAB. It is important to note that this does not mean that the EAB is vulnerable to attacks, as even in this case the enemy will be forced to allocate significant assets for the destruction of a small and temporary asset.

3. Exact Model: Lower-Bound for the Probability of an Incoming Salvo Destroying at Least Two Aircraft

a. Model Description

In the best case, it can be imagined that the enemy will not be able to target any aircraft specifically, but rather decides to uniformly distribute their shots within their perceived area of the EAB. This implies that the enemy will divide the perceived area of the EAB into cells that can be destroyed by a single strike. In that case the probability of a missile hitting an aircraft is determined by the probability of an aircraft being present in a cell that was picked. The result for this model depends on the perceived size of the EAB. For this model it was assumed that the enemy believes aircraft in an EAB to be

distributed over an area of 1,000,000m². For that case the number of cells depends on the lethal radius of the warhead (206 ft. for unitary warhead and 575 ft. for dispersible warhead). An illustration of the model may be seen in Figure 40.

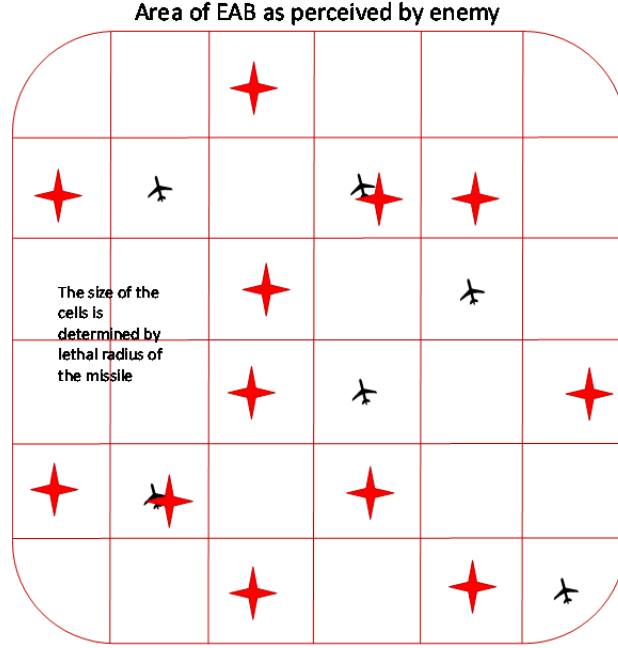


Figure 40. Area of EAB as perceived by the enemy.

The number of cells out of which the enemy chooses targets is:

$$\#_{\text{cells in enemies perceived area of EAB}} = \frac{A_{\text{EAB according to enemy perception}}}{R_{\text{lethal}}^2}$$

Due to the mathematical result of the model, the number of aircraft hit is distributed according the hyper-geometric distribution.

$$\#_{A/C \text{ hit}} \sim \text{Hypergeometric}(\#_{\text{occupied cells}}, \#_{\text{cells}}, \#_{\text{missiles}})$$

The probability of hitting at least two targets is given by

$$p_{\text{at least 2 A/C destroyed}} = 1 - CDF_{\text{hypergeometric}}(1, 6, \#_{\text{cells}}, 12)$$

b. Model Results

Design	EAB area	Warhead	Prob. Of 30% destruction with salvo of 12 missiles
Single	1,000,000 m squared	Unitary	3%
Single	1,000,000 m squared	bomblets	67%

Table 4. Lower bound results for Probability of 30% destruction with 12 missiles.

These results give a lower bound for the actual probability of destruction with a salvo of 12 missiles. These results show that if the enemy is unable to target any individual aircraft, he may be unable to be effective in attacking an EAB. This favorable result shows that it is important to make the enemy believe that EABs are as large as possible so that the enemy spreads their shots wide. In these results it is again apparent that the enemy warheads' lethal radius has a significant effect on their effectiveness. A dispersible warhead with a lethal radius of 575 feet is most likely effective for attacking an EAB, unless some form of quickly deployed barricade is used to protect vital assets.

4. Simulation Model

a. Description

The presented simulation model is a location-based Monte Carlo simulation for locating the incoming strikes in a salvo, and comparing it to the layout of an EAB. The model requires, as parameters, the layout of an EAB for the blue force, and the missile accuracy, targeting accuracy, aim-point selection logic, lethal radius, and salvo size of the red force. Results reported are based on 10^6 independent trials.

The model can be used to compare different layouts for an EAB to find which will require more missiles to achieve a certain effect. It can also be used to study the effect of camouflage on the enemy's ability to strike an EAB, and to assess the risk at the EAB from different targeting sources.

Assumptions:

- The aim-points are selected to aim at the highest priority target visible. Target priority is aircraft first, maintenance facilities second, and runway last.
- Salvo size is calculated to ensure that the enemy's probability of a salvo destroying at least 30% of the aircraft is over 80%.
- Lethal radius for unitary warhead is 206 ft. while the lethal radius for a warhead containing dispersible bomblets is 575 ft. (Stillion and Orletsky 1999).
- Targeting accuracy is based on human visual observation capabilities of an EAB from a distance of 3000 meters. The modeling assumption is that ground security forces of an EAB will be able to stop any attempts to observe the EAB from a distance of 3km or less.
- In a salvo of missiles, the enemy will fire all rounds in a nine-point square pattern around the aim-point, with spacing equal to the lethal radius of a single missile. This assumes that the enemy will know that the vital assets in an EAB are physically separated, a conservative assumption. If the enemy directs all fire towards the same location actual probabilities of hit will be lower.
- All aircraft are in their designated parking during attack. This conservative assumption does not take into account any aircraft that may be airborne when an incoming attack occurs.

b. EAB Layout

Different layouts of an EAB were tested to determine which is better for the protection of vital assets. The comparison of the different layouts was performed according to two measures of effectiveness: the number of missiles in a salvo required to achieve 30% destruction of two aircraft with an 80% chance; and the probability of hitting at least two aircraft with a salvo of 10 missiles.

Two essentially different layouts were tested. The first was a layout design in which planes were parked in two rows along the runway, where the distance between the rows and the inter-aircraft spacing in the row was varied to give several different layouts from the same design. The second design tested was a single row along the runway. The inter-aircraft spacing was also varied in this design to result in several actual layouts to be tested. The two layout designs are shown in Figure 41. and Figure 42.

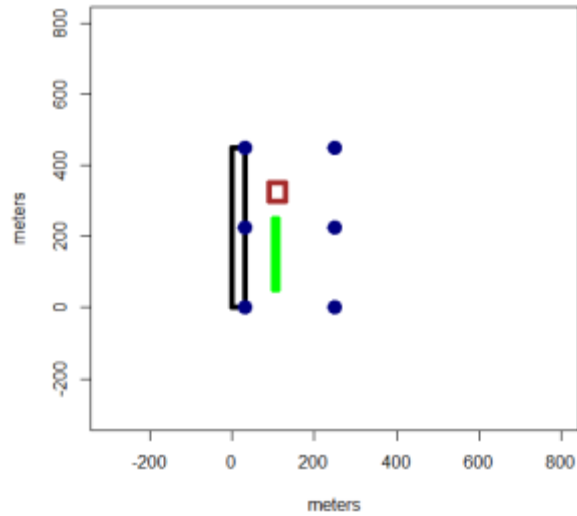


Figure 41. Two row EAB design.

In Figure 41 the blue dots mark the parking space for aircraft, the red square marks the maintenance facility, and the green line marks the location of the personnel trenches and the black rectangle marks the runway. Spacing between aircraft is 225m. In the marking are the same but the spacing between aircraft is 115m.

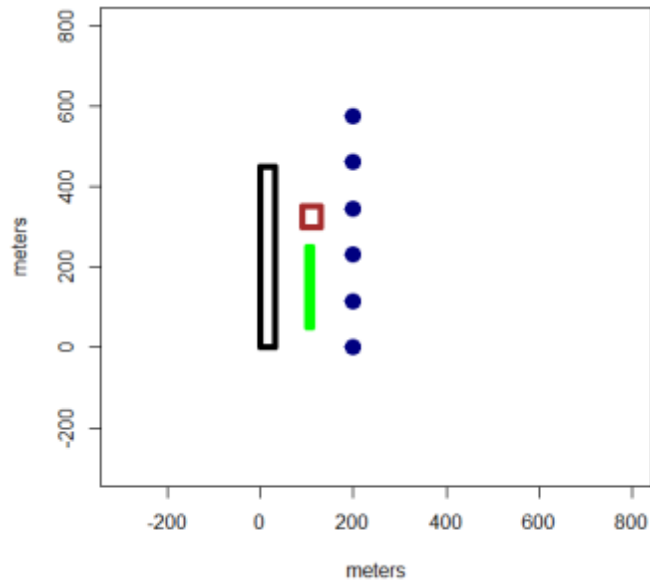


Figure 42. Single row EAB design.

In Figure 42. the blue dots mark the parking space for aircraft, the red square marks the maintenance facility, and the green line marks the location of the personnel trenches and the black rectangle marks the runway. Spacing between aircraft is 115m.

c. *Effect of Camouflage*

The model was also used for testing the effect of camouflage. This was performed by assuming that it was not possible for the enemy to directly target camouflaged assets. The enemy's targeting was based on the following priority: aircraft first, maintenance facilities second and runway last.

d. *Effects of Various Enemy Capabilities*

Each layout was tested for two cases of enemy missile capabilities, and for two cases of enemy targeting capabilities. With regard to missile capabilities a unitary warhead was tested along with a warhead of 1lb bomblets. The unitary warheads weigh 1,100lbs, and have a lethal radius of 206 feet. The sub munition has a 1,100lbs warhead containing 825 1lb bomblets, with a total lethal radius of 575 feet.

5. Results

Table 5. shows the results from this simulation model.

Design	Spacing	Warhead	Targeting	Aim-point	Salvo req. for 30% destruction with 80% prob.	Prob. of 30% destruction with salvo of 10 missiles	Fig # in Annex X
Single	50 m	Unitary	HUMINT	A/C 3	5	99%	3
Single	100 m	Unitary	HUMINT	A/C 3	8	89%	4
Single	150 m	unitary	HUMINT	A/C 3	12	69%	5
Single	200 m	unitary	HUMINT	A/C 3	22	47%	6
Double	50 m	unitary	HUMINT	A/C 2	4	>99%	7
Double	100 m	unitary	HUMINT	A/C 2	6	97%	8
Double	150 m	unitary	HUMINT	A/C 2	9	87%	9
Double	200 m	unitary	HUMINT	A/C 2	13	67%	10
Single	50 m	unitary	HUMINT	Runway	17	53%	11
Single	100 m	unitary	HUMINT	Runway	26	37%	12
Single	150 m	unitary	HUMINT	Runway	36	20%	13
Double	50 m	unitary	HUMINT	Runway	9	84%	14
Double	100 m	unitary	HUMINT	Runway	7	92%	15
Double	150 m	unitary	HUMINT	Runway	9	84%	16
Double	200 m	unitary	HUMINT	Runway	14	64%	17
Single	200 m	bomblets	HUMINT	A/C 3	3	98%	18

Single	300 m	bomblets	HUMINT	A/C 3	10	81%	19
Double	200 m	bomblets	HUMINT	A/C 2	2	>99%	20
Double	300 m	bomblets	HUMINT	A/C 2	5	95%	21
Double	400 m	bomblets	HUMINT	A/C 2	11	76%	22
Single	200 m	bomblets	HUMINT	Runway	10	80%	23
Single	300 m	bomblets	HUMINT	Runway	28	56%	24
Double	200 m	bomblets	HUMINT	Runway	3	>99%	25
Double	300 m	bomblets	HUMINT	Runway	5	93%	26
Double	400 m	bomblets	HUMINT	Runway	12	74%	27

Table 5. Monte Carlo simulation results for EAB Layout comparison model.

A summary of these results and derived insights are described in the following section.

6. Model Conclusions

a. *EAB More Protected than CVN*

The first and most important conclusion that is drawn from this model is that an EAB is inherently more secure against incoming missile strikes than a CVN would be, even without active defenses. In order to effectively strike an EAB and stop its operations the enemy would be forced to launch a salvo with a size on the order of 10 missiles. Even then, based on the previous analyses, the number of aircraft that would actually be destroyed is likely to be relatively small, that is, between one and six aircraft. It may be stated that use of an EAB will force the enemy to expend significantly more than one Medium Range Ballistic Missile (MRBM) for each aircraft on the ground, even considering that every salvo launched will have a valid targeting solution for an active EAB.

b. *EAB Design*

The results clearly show that single row parking is preferable to parking aircraft in a double row, under the assumptions of the model. In addition, it is clear that larger spacing between aircraft allows for significant reduction in the amount of damage expected from an incoming salvo. These two results make up the EAB design trade-space, depending on how plausible it is to operate an EAB that spans a larger distance.

However, from a protection point of view it is clear that the larger spacing reduces damage.

In order for the spacing to be effective it should be on the order of the lethal radius of the enemy warheads. The results shown here are calculated for a given warhead size, but can be extended to any arbitrary warhead according to the expected scenario.

The effects of camouflaging vital assets (aircraft, maintenance facilities and personnel) are important as they significantly impair the enemy's targeting capabilities and reduce their damage model to "area fire." This will become even more important as technology evolves, and enemy missile accuracy and targeting accuracy increase.

The model has not taken into account the reduced lethality of warheads that may be achieved by parking aircraft in quickly erected barricades or hardened facilities to reduce blast effects.

c. Ground Defense

Assuming that targeting solutions of an EAB will be achieved via HUMINT sources, ground defense becomes an important aspect of defense against ballistic missile strikes. The distance at which an observer stands from the target has a strong effect on the accuracy of targeting that he/she may perform. If ground defense increases the distance at which observers stand, the accuracy of targeting will be reduced, which can have a significant effect on the total damage caused during a missile attack. A more precise quantification of this effect will require follow-on analyses.

C. EAB SUCEPTIBILITY ANALYSIS

1. Introduction

This study focuses on the probability of an EAB being located by enemy's spy satellites. Based on open source information, China currently has 25 satellites operating in Low Earth Orbit (LEO), each operates at an altitude ranging from 600km to 1100km, and each completes an orbit in approximately 90 minutes (ITPROSTAR 2014). And, it has been reported that China is planning to have 50 satellites by 2020 to increase their sources of the earth observation data (ITPROSTAR 2014).

As these satellites pose a threat to the deployment of the EABs, this study aims to assess the probability of locating an EAB as well as factors that change or affect the probability. An analytical model is first developed to derive the upper and lower bound of the probability of being located based on the satellites' orbit. Further analysis is then carried out through Monte Carlo simulations to assess the effect on the probability due to factors such as decoy usage, and EAB deployment duration. Each simulation is performed repetitively to determine the probability of being located, which is obtained from the proportion of the number of located EABs to the total number of deployed EABs.

2. Analytical Model

The formulation of the model provides a first-hand insight on the EAB's susceptibility. A group of satellites can be configured to work together as a satellite constellation. Such configurations coordinates the movement of each satellite, thus increasing the ground coverage. Hence, if China has configured or is planning to configure (in the future) a satellite constellation, the EABs will run a higher risk of being identified.

This analysis aims to explore the EAB's susceptibility, i.e., probability of an EAB being swept, when faced with a satellite constellation. The analysis shall first establish the probability based on the amount of ground covered by an uncoordinated set of satellites (i.e., worst case for China – lower bound). And secondly, to evaluate the probability based on the ground coverage on a coordinated (i.e., best case for China – upper bound) satellite constellation. These bounds shall also be used to validate the results obtained from the Simulation model in the next section.

a. Sweep Width of China's Satellites

A commercial satellite, LANDSAT 8, has a sweep width of 185 km (operating at altitude of ~705km) and is capable of producing imagery in 30m by 30m pixel resolution (Satellite Imaging Corporation 2014). The target to identify in this scenario context is an F-35B, which is 11m by 16m; therefore China would require imagery of at least a 3m by 3m pixel resolution to locate the F-35B.

As it is extremely conceivable that China will invest a lot in the optics of their satellites' sensors, the target of acquiring such clear imagery will definitely be achieved in the near future. Hence, this study assumes that, with the continual technological advances and investments, China will be able to develop and operate with satellites' sensors that have a sweep width of 37km and are capable of producing imagery to identify the F35-B.

b. Probability of Sweeping an EAB

From a study conducted by Naval Research Laboratory, a satellite operating at an altitude of 475.30nmi (~880.25km) which completes 14 revolutions each day, requires a minimum sweep width of 722.81nmi (~1430km) to be able to scan the entire earth (Eisele and Nichols 1976).

Hence, the proportion of a swept region is equal to the sweep width of a satellite divided by the minimum sweep width. And, this proportion is also equal to the probability of sweeping an EAB if it is deployed within the sweep region. Based on the assumption made for China's satellite, with a sweep width of 37km, the probability of sweeping an EAB is 2.59% (37/1430) per pass.

(1) Uncoordinated Constellation (China's Worst Case - Lower Bound). If the satellites in a constellation operate in a random or individual fashion, the probability of sweeping an EAB in a pass is 2.59%. In the context of this study, if an EAB is deployed for a three day period, China's 25 satellites will have a total of 75 passes during this period. Hence, by treating each pass as a Bernoulli trial with probability p of 0.0259, based on the Binomial distribution (Hayter 2012).

$$P(\text{Sweeping an EAB in a 3 day period}) = \text{Proportion of Area Swept in 3 days} \\ = 1 - (1 - 0.0259)^{75} = 0.86$$

Therefore, the lower bound of the probability of sweeping an EAB deployed for a three day period is 0.86.

(2) Coordinated constellation (China's Best Case - Upper Bound). It was mentioned that a satellite will require a minimum sweep width of 722.81nmi (~1430km) to be able to scan the entire earth. Hence, with a sweep width of 37km, if China is able to coordinate their constellation in such a way that each satellite covers a unique portion of the 722.81nmi wide area, they will be able to sweep the entire area almost twice.

$$P(\text{Sweeping an EAB in a 3 day period}) = \text{Proportion of Area Swept in 3 days} \\ = 75 \times 0.0259 = 1.94$$

Therefore, the upper bound of the probability of sweeping an EAB deployed for a 3 day period is 1.00.

In summary, the analysis shows that the EAB has a very high risk of being swept. However, it should be noted that the probability of sweeping over the EAB does not necessarily guarantee detection. Since in practice, there are imperfect sensors.

3. Simulation Model Formulation

A simulation model was developed with the objective of assessing the probability of being located when the following factors were varied:

- A. Duration of stay at a specific location.
- B. China's continual increase of spy satellites in operation
- C. China's continual improvement in sensor capabilities to improve the sweep width of satellites
- D. Using "false" EABs as decoys

a. Entities

This model consists of three entities: the area of conflict, the satellites, and the EABs. The characteristics of each entity shall be discussed in the following sections.

(1) Entity: Area of Conflict (AOC). In the context of this study, the AOC is defined as any land area around the South China Sea where an EAB could be positioned. In this model, the AOC is divided into 356 by 333 grids, where each grid has an area of 7.4km by 7.4km.

(2) Entity: EABs. Each EAB can be randomly positioned into each of these grids divided in the AOC. A number of 20 EABs is assumed for each simulation unless stated otherwise.

(3) Entity: Satellites. This model assumes that China has a total of 25 spy satellites capable of producing imagery that aids in locating an EAB. And as mentioned earlier this model assumes that all China's satellites have a sweep width of 37km.

- Azimuth of Satellite Path

The azimuth of the satellite path is deduced from the movement of a Chinese satellite across the AOC. The azimuth is calculated via the use of samples of the satellite's coordinates. It is approximated to be 12.48° , 167.52° , 192.48° or 347.52° (0° towards true north in the clockwise direction) depending on its AOC entry position. In this model, the collection of satellite paths is limited to an azimuth of 77.52° or 192.48° . As the area which is swept by a path with 167.52° and 192.48° is similar to the areas with 347.52° and 12.48° , that limitation simplifies the model. And due to the pre-defined size of each grid (7.4km by 7.4km) in the model's AOC, the azimuth is further adjusted to 168.7° and 191.3° to simplify the process of determining the grids that the satellite will sweep. See Figure 43 and Figure 44 for the azimuth of satellite path.

- Number of Passes across AOC

As mentioned earlier, each satellite is assumed to have three passes of the AOC per day.



Figure 43. Azimuth of satellite path (map and Directions of Arrows are not drawn to scale).

In summary, the following characteristics of China's spy satellites are assumed for all simulations unless stated otherwise:

- Sweep width: 37km
- Probability of sweeping AOC in each revolution: Sweep width divided by 722.81nmi ($\sim 1430\text{km}$).
- Number of revolutions of each satellite per day: 14
- Number of passes per region per satellite per day: 3

b. Simulation Implementation

The Monte Carlo simulation was developed using a statistical computing tool, R (R Core Team 2013). Each run randomly replicates the deployment of the EABs and movement of the satellites. Each run is designed to model three days' worth of EAB deployment.

(1) Deployment of EAB. The deployment of the EABs is first conducted by generating random values to assume the grid location of the EABs in the AOC.

(2) Movement of Satellite. For the three passes assumed for each satellite, a grid position was generated as the AOC entry position of the satellite. The path of the satellite was then formed based on the AOC entry position, the azimuth of the path, and the satellite's sweep width. Any EABs that falls within the path was considered swept.

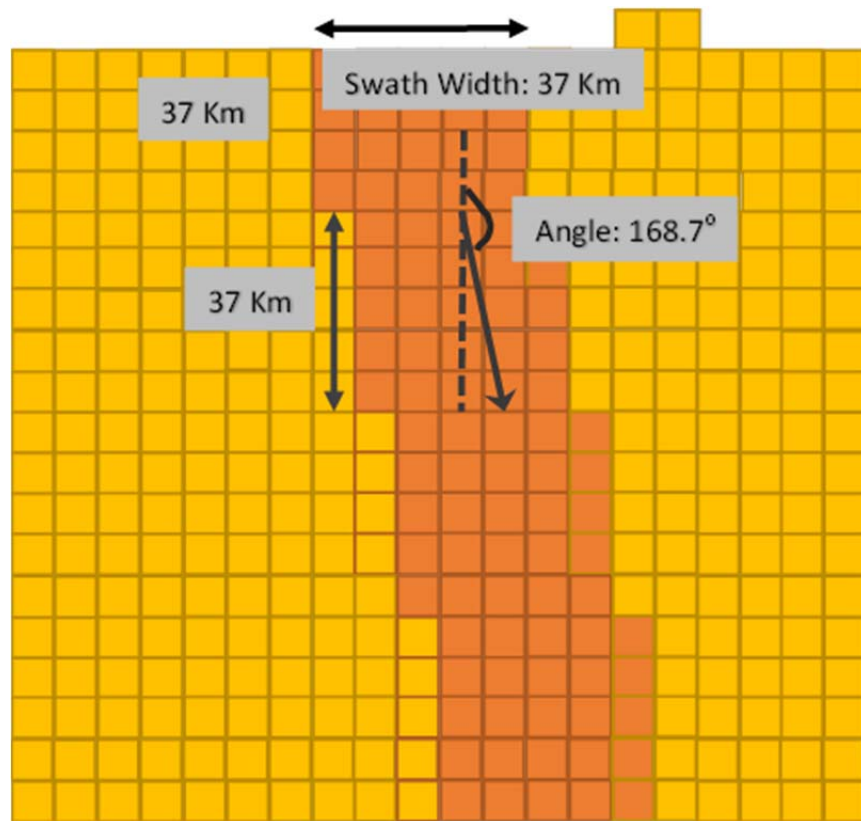


Figure 44. Illustration of a satellite path with Azimuth of 78.7°.

4. Simulation Results

This section discusses the results of the four analyses that were conducted using the simulation model.

a. Analysis A: Various Duration of Stay at a Specific Location

This simulation aimed to analyze the effect of an extended stay of an EAB at a specific location. As such, the duration of stay was varied between one and six days.

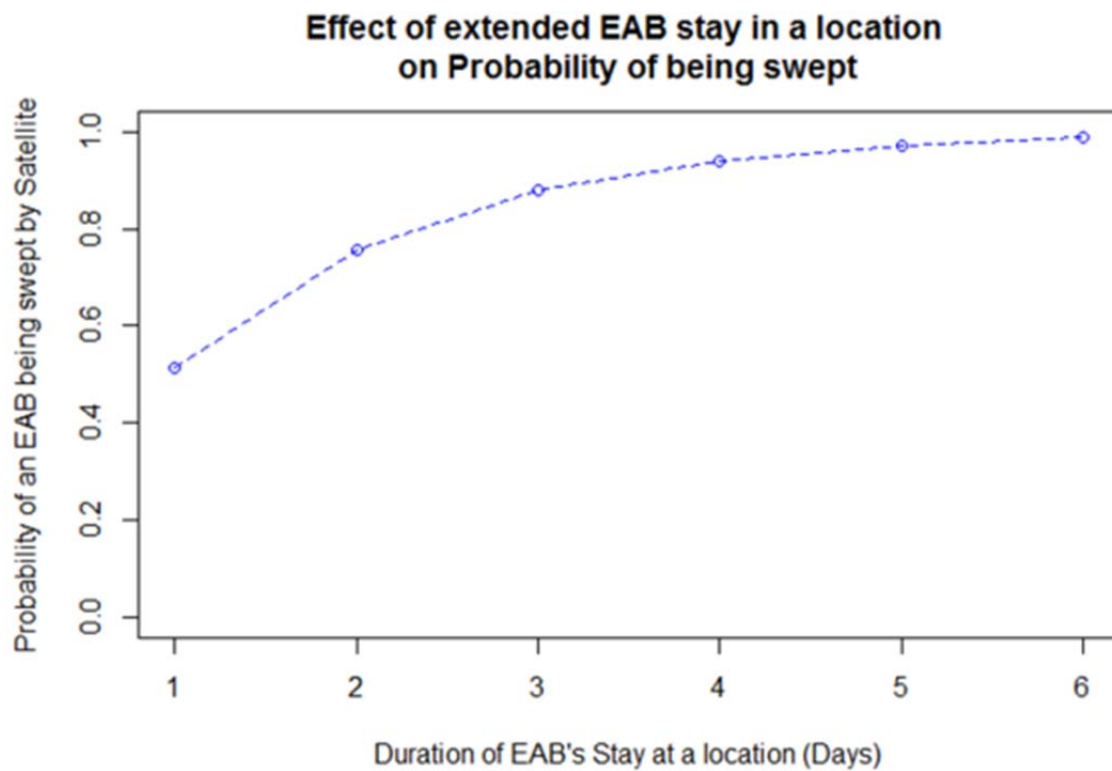


Figure 45. Effect of extended EAB stay in a location on probability of being swept, i.e., observed

The effect of the increase in the duration of stay at each EAB is shown in the Figure 45. It can be clearly seen that the longer the duration of the stay, the higher the probability of being located. A huge jump (~25%) in the probability is observed when an EAB extends its stay from day 1 to day 2. Hence, the result of this analysis highlights the importance of reducing the duration of stay. If the deployment is extended for a long

period, it will be necessary to employ deceptive operations such as “decoy EABs” and level of activity fluctuations at each EAB.

b. Analysis B: China’s Continual Increase of Spy Satellites in Operation

This simulation aimed to analyze what affect the threat of China’s continual increase of satellites has on the deployment of EABs. As such, the number of satellites was varied between 10 to 24 satellites.

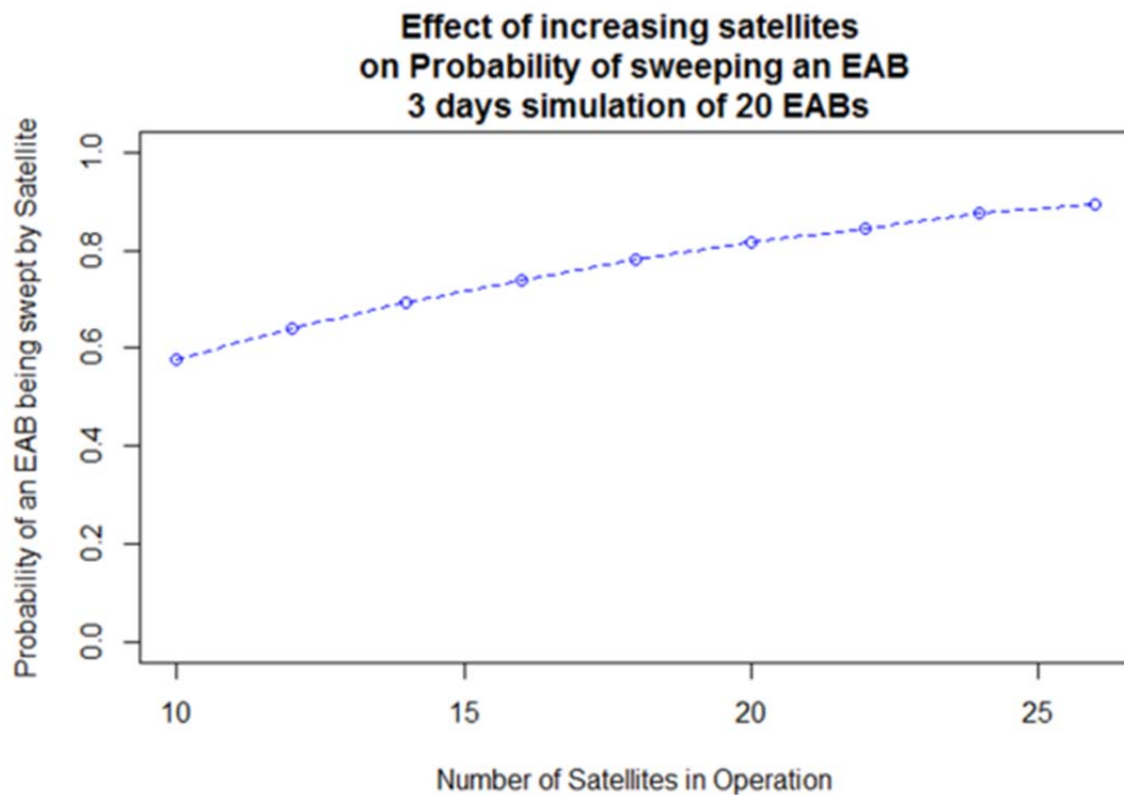


Figure 46. Effect of China’s continual increase of spy satellites in operation.

The effect of the increase in the number of satellite sensors is shown in Figure 46. In the context of improving the probability of identifying EABs, it can be seen that the return on investment of putting more satellites into space is significant. A heavy investment of a two-fold increase in numbers results in a significant increase of 10% for the probability of sweeping an EAB. Hence, if China is able to achieve their strategic

goal of having 50 satellites in space (Pangburn 2014) the EABs run a higher risk of being identified.

c. Analysis C: China's Continual Improvement in Sensor Capabilities to Improve the Sweep Width of Satellites

This simulation aimed to analyze the effect of China's continual improvement in their satellite's sensor capabilities on the deployment of EABs. As such, the magnitude of the satellite's sweep width is varied between 7.4km to 74km.

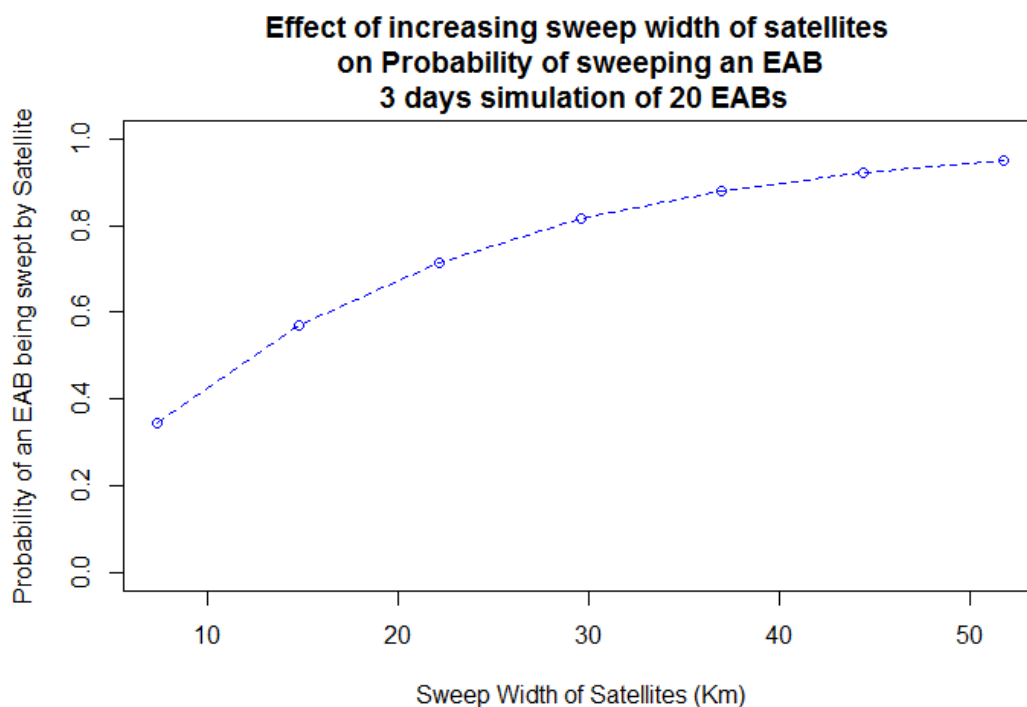


Figure 47. Effect of China's continual improvement in satellite sensor capabilities.

The effect of the increase in the capability of satellite sensors is shown in Figure 47. As the sweep width of the satellite becomes higher, it corresponds to a higher probability of locating an EAB. From the plot, a sweep width of 30km corresponds to a probability of 80%. Depending on sensor technology advancements, if China is able to produce a satellite which has a sweep width of 50km capable of producing 3m by 3m pixel imagery, they will be able to identify an EAB within three days.

As this study assumes that China’s satellites have a sweep width of 37km, it may contrast with their actual capability. Hence, it may be necessary to perform a study to evaluate the actual capability of their satellite sensors.

d. Analysis D: Using “false” EABs as Decoys

This simulation aimed to analyze the effects of using “False EABs” as decoys. The ratio of “False EABs” is varied in the simulation from 0.0 to 0.6 of the total number of EABs in operation.

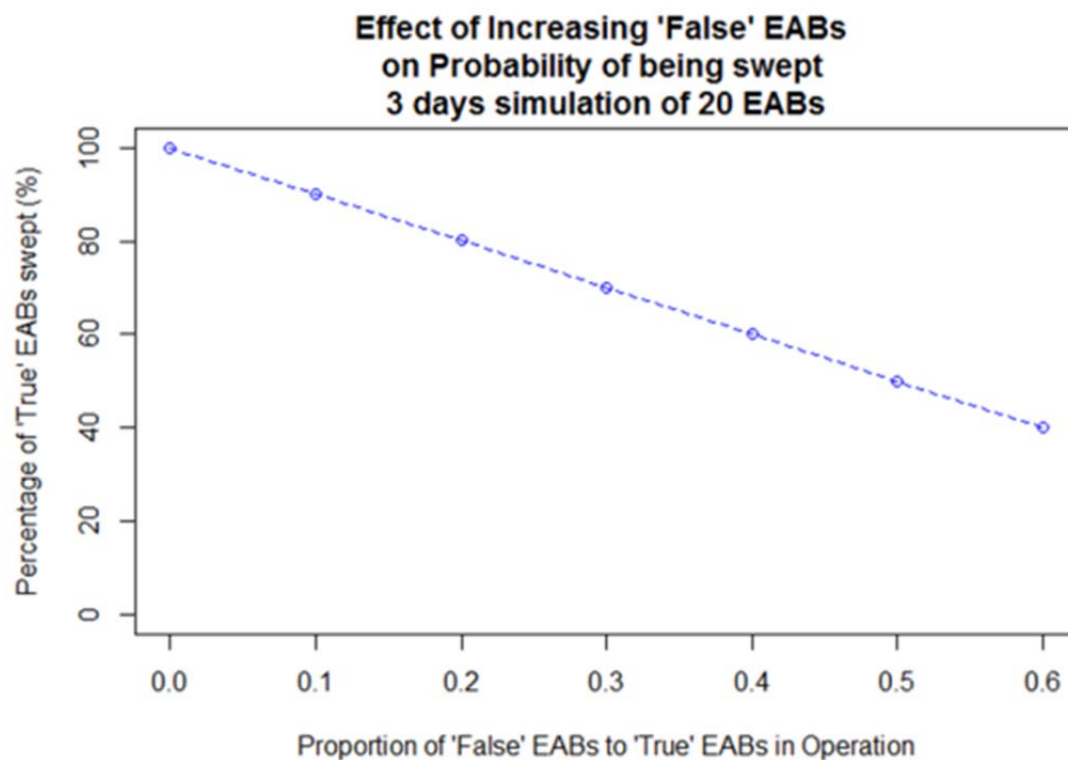


Figure 48. Effects of using “False EABs” as decoys

The effect of using “False EABs” as decoys is shown in Figure 48. From the plot, it can be deduced that for each 10% increase in the proportion of “False” to “True” EABs, it reduces the chances of locating a “True EAB” by 10%.

The results highlight the importance of introducing “False EABs” as decoys as it can significantly reduce the probability of a “True EAB” being swept. In addition, the

identification of a “False EAB” may also lead to time-consuming efforts by China to further confirm the EAB’s existence, or further, a wasted salvo against a non-existent EAB.

5. Conclusion

This study does raise some concerns with regards to the susceptibility of EABs. Based on the analysis, the EABs could be located by China’s current strength of satellites within a few days. And, their continual investment of putting up more satellites into space would further improve the surveillance of the conflict area. However, the study did show that the use of decoy operations could reduce the probability of an operational EAB being located. Hence, strategies such as decoy operations, camouflaging methods, and fluctuating levels of activities should be further evaluated for feasibility to enhance the concept of EAB deployment.

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VIII. DAW SOLUTION PART 2: THE SEA SCOUT CONCEPT

A. CHAPTER SUMMARY

This Sea Scout chapter outlines the analytic process that started with a Naval Air Warfare Center concept known as Sea Vex and resulted in the SEA 20B re-design and renaming of that concept. After the SE process determined the high level functions and requirements for providing naval air capability in an advanced A2AD environment, the team determined that it was necessary to reengineer the Sea Vex design to better fit into the architecture of the overall naval air force structure. The goal of the redesign was to maintain the advantages of the original design while addressing its challenges in a manner that would allow for an IOC around the 2025–2030 timeframe.

Sea Scout is a system designed to meet the requirement of distributing airborne ISR, Land Strike and Surface Strike capabilities throughout the Fleet. It comprises two main elements – a small UAS courier ship and embarked airborne platforms – that offer these three primary warfighting capabilities.

The UAS courier vessel, also known as CVE, is about 1/3rd the size of CVN and requires only 16% of the CVN/CVW crew to man, has a speed of up to 50 knots, and is coupled with point defense capabilities and soft kill measures (Levine et al. 2013).

Sea Scout provides ISR capability, in the proposed construction, via an airborne asset such as the A160 Hummingbird, a rotary wing autonomous UAS. Among the full spectrum of ISR missions, use of the Hummingbird also provides the fleet with surface early warning and over-the-horizon targeting capabilities that enable extended range anti-ship cruise missiles and land attack missiles to reach their full capability in dynamic targeting scenarios. Its capability is far superior to any platform of its type and weight class boasting a 222 knots maximum speed, 2,500+ nm range, 20+ hour endurance, 2,500 lbs. payload capacity and full complement of integrated sensors.

Strike capability is designed into Sea Scout with the utilization of current and emerging state of the art cruise missile technology via the Tactical Tomahawk Land Attack Missile (TLAM) and the Long Range Anti-Ship Missile (LRASM). These platforms are integrated into the system by the use of 14 Mk 57 next generation Vertical

Launch Systems. With the Mk 57, Sea Scout brings a tailored mixture of up to 56 strike missiles to the fight.

Whether attached to a SAG or CSG, Sea Scout delivers critical distributed capabilities wherever and whenever the fleet needs them the most.

B. CONCEPT BACKGROUND (SEA VEX)

At a very early point in the project timeline a solution alternative known as Sea Vex was presented to the team for further analysis by the Naval Air Warfare Center as a viable way of projecting and distributing naval air power across the fleet. Sea Vex is a system-of-systems concept comprising two types of platforms, the first being a small escort-sized UAS carrier (CVE-X or CVE) and a compliment system of various UAS platforms that would launch and recover from the CVE. The UASs carried onboard would be capable of executing a variety of missions currently accomplished by today's manned CVW assets representing distributed air wing capabilities. The primary goals of the concept are to reduce the acquisition and operating costs associated with current naval air systems, reduce the risks of operating in an A2AD environment, and maintain most or all of the CVW's current mission capabilities.

The 2013 Fall Quarter Total Ship's Systems Engineering (TSSE) class at the Naval Postgraduate School designed a specific platform for the CVE which will be referenced from here forward in regard to the ship design (Levine et al. 2013). Compared to a CVN, a CVE is a much smaller and has a less ambiguous visual signature and radar cross section. The TSSE design requirements state that the vessel will be 320 feet long and 90 feet wide, about one-third the size of a CVN (Levine et al. 2013). Also, it will displace ~4000 tons compared to today's *Nimitz* class CVN which displaces ~100,000 tons (Levine et al. 2013).

The CVE is also designed to be faster than today's CVN. With its catamaran style hull, the TSSE report predicts that it could reach speeds as fast as 50 knots, compared to the CVN's published 30+ knots (U.S. Navy 2014) (Levine et al. 2013). Given both the CVE's small size and speed, when combined with the appropriate sensors and

countermeasures, the risk of being targeted by A2AD threats such as ASBMs and submarines could be greatly reduced.

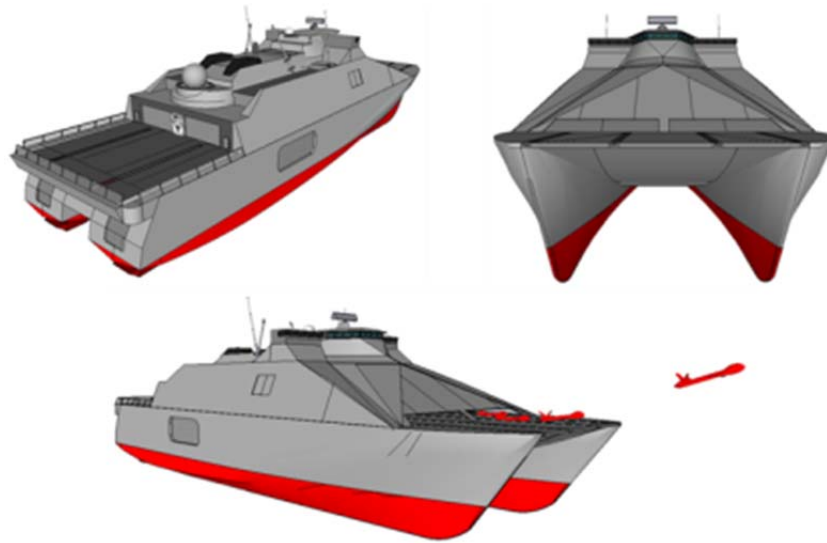


Figure 49. CVE launching embarked UAS assets (from Levine et al. 2013).

The CVE platform design is also significantly cheaper than the traditional CVN/CVW to build and man. From the TSSE analysis, it was estimated that the cost of the CVE, including its air component, would be about \$710M (FY14), which would be about 1/8th the cost of a Nimitz Class CVN without its air wing (Levine et al. 2013). The design calls for a crew complement of 40 personnel with an additional 60 members to manage the UAS systems (Levine et al. 2013). For the acquisition cost of a single CVN, eight CVEs could be purchased with a total manning requirement of 800 personnel versus the 5000+ personnel required to man the current CVW/CVN system. That is about 16% of today's CVN/CVW manning. This reduced manning coupled with the smaller size and increased agility of the vessel could significantly reduce risk in regard to the loss of human life and assets in the A2AD environment.

In regard to the Sea Vex concept's unmanned air wing, the concept calls for the use of small scale UASs to represent capabilities currently filled by manned platforms within the traditional CVW. These UAS platforms would be modified BQM target drones that would be configured to perform a wide range of naval air missions while launching

and recovering from the CVE platform. See Table 6. The baseline vision includes the following missions (Naval Air Warfare Center Weapons Division 2013):

- Fleet Scout/Reconnaissance
- Electronic Support Measures
- Electronic Warfare
- Decoy
- Precision Strike
- Communications/Network Relay
- Fleet Air Defense
- Fleet Training

Use of these small and inexpensive BQM air vehicles could potentially provide an economic means of distributing naval air capability across a Surface Action Group or Carrier Strike Group in the absence of or in concert with traditional CVW assets.



			
	BQM – 34S	BQM-177A	BQM-74E
Dimensions (L x W)	22.9' x 12.9'	17' x 7'	12.95' x 5.78'
Weight: dry/max (lbs.)	2150/3100	520/1400	455
Capability:			
Altitude (ft.)	60,000	45,000	40,000
Speed (kts)	625	700	515
Endurance (min)	115	115	78
Range (NM)	350	500	350
NAV	GPS/INS/IMU	GPS/IMU	GPS/IMU
Mission	<ul style="list-style-type: none"> • A/C sim • Sub-sonic Missile sim 	<ul style="list-style-type: none"> • A/C sim • Sub-sonic Missile sim 	<ul style="list-style-type: none"> • A/C sim • Super-sonic Missile sim
Cost (per unit)	\$897K	\$670K	\$342K

Table 6. BQM platforms considered for Sea Vex (from Levine et al. 2013).

The Sea Vex concept provides advantages beyond just size, cost and speed. Another important advantage to Sea Vex is the idea of distributing naval air capabilities. Multiple CVE platforms dispersed throughout the maritime environment would provide

the fleet with access to air power over a much wider swath of the battle space by attaching air capability directly to Surface Action Groups, Surface Flotillas, Amphibious Ready Groups, Marine Expeditionary Units and even Carrier Strike Groups. By accomplishing this, naval assets would no longer be constrained to staying within range of the CVW when air capability is required to complete the mission. With a dedicated CVE platform assigned to the group, air capability is always on station wherever and whenever it is needed. Distribution also adds to tactical flexibility as the number of CVE platforms could be tailored to the situation by adding or subtracting vessels from a group to adjust for combat capacity.

As a direct result of the distributed capabilities of the Sea Vex concept, another important advantage that it brings to the table is the physical dispersion of assets across the battle space. As mentioned in the problem statement discussion, the present method of placing an entire CVW on a single CVN is problematic as it allows for a single-point-failure in regard to the naval air wing. However, naval air capabilities brought to the fight by a squadron of CVE platforms dispersed across the fleet would be significantly more difficult to for the enemy to detect, identify, target and neutralize.

C. SEA VEX CHALLENGES

While there are certainly many advantages that the Sea Vex concept brings to the solution space, the team also noted several challenges that needed to be considered.

Sea Vex calls for large levels of autonomy in both ship and UAS operations; however, heavy reliance on autonomy in system design also poses significant risk. This is because effective autonomous technology in regard to both shipboard and UAS operations is still a long way from being perfected. For example, during the autonomy discussion several team members cited the case of the Littoral Combat Ship (LCS), which is heavily debated and studied throughout NPS. The ship was required to operate with a crew of 40 sailors by relying on a significant amount of autonomy designed into the system to meet this manning requirement. Today, shortcomings in autonomous technology have resulted in additional manning requirements requirement (Fellman 2012).

For example, the original 40 crew concept of LCS left significant operational gaps (Fellman 2012). Considering the lessons of LCS, the team consensus was that reliance on heavy automation should not be a major design consideration unless that technology has been developed and demonstrated in the operational environment (TRL 7 or higher).

The team also considered the present maturity level of UAS platforms as a total system in regard to the wide spectrum of naval air mission sets, and it was determined that overall UAS technology is fairly immature in this respect. A general observation, given an unclassified survey of current UASs in the U.S. military performed by the team, highlighted that today's operational UASs do not represent a very significant amount of capacity and capability when compared to manned assets. Other than ISR and small volume Strike and Decoy capabilities, the survey could not find reference to UASs that successfully provide a significant capacity of other critical capabilities to include Offensive and Defensive Counter Air, Airborne Electronic Warfare, Airborne Anti-Submarine Warfare, Anti-Mine Warfare, Airborne Early-Warning, or myriads of other capabilities currently covered by manned assets. Also, the ISR and Strike UAS platforms that are operational today have not been proven in a non-permissive environment where survivability is a key attribute.

Given the relative immaturity of UAS technology and the short time in which the system needs to be operational (2025–2035 time frame), the team concluded that the initial installment of the Sea Vex concept would be very limited in the capacity and capability it could provide to the fleet.

While the reduced size and tonnage of the CVE design is advantageous in regard to cost, speed, and probability of being targeted, the associated space-limitations present significant challenges to the amount of air capability that can be carried onboard the CVE. Its small dimensions restrict both the size and number of aircraft that can be stored and operated on a single vessel. This restriction is significant because, it was noted during the UAS survey, that greater capability and capacity generally requires larger sized air vehicles, especially in regard to payload, range and endurance as seen in Table 7.

UAS Vehicle	Rotary Diameter /Wingspan	Length	Range	Endurance	Payload	Capabilities		
						STRIKE	AIR	ISR
RQ-2A Pioneer (IHS Jane's 2010)	17' 1" (5.2 m)	13' 1" (4.00 m)	100 nm	5 hrs.	none			X
MQ-8A/B Fire Scout (IHS Jane's 2014)	27.5' (8.4 m)	23.95' (7.3 m)	110 nm	5 hrs.	600 lbs.	X		X
RQ-8C Fire Scout (Trimble 2014), (IHS Jane's 2014)	35' (10.67 m)	41' 8" (12.7 m)	324 nm	14 hrs.	700 lbs.	X		X
BQM-74E (NAVAIR 2005)	5' 9" (1.76 m)	12' 11" (3.94 m)	350 nm	1 hrs.	80 lbs.			
BQM-177 (Levine et al. 2013)	7' (2.13m)	17' (5.18m)	500 nm	1.9 hrs.	200 lbs.			
Scan Eagle (IHS Jane's 2014)	10' 2" (3.11 m)	5' 7" (1.71m)	62 nm	24 hrs.	none			X
BQM-167 (Meyer 2005)	10.5' (3.2 m)	20' (6.09m)	NA	NA	NA			
BQM-34S (NAVAIR, PMA 208: Aerial Target and Decoy Systems n.d.)	12.9' (3.93m)	23' (7.01m)	350	1.9 hrs.	90 lbs.			
MQ-9 Reaper (IHS Jane's 2013)	65' 7" (20 m)	36' 1" (11 m)	4,600 nm	32 hrs.	3,000 lbs.	X		X
MQ-1 Predator (US Air Force 2014)	48' 8" (14.8 m)	27' (8.22 m)	675 nm	24 hrs.	1,000 lbs.	X		X
X-47B UCAS-D (IHS Jane's 2014)	62' (19 m)	38' (12 m)	2,100 nm	NA	4,500 lbs.	X		X
RQ-170 Sentinel (IHS Jane's 2014)	66' (20 m)	14' 9" (4.50 m)	NA	NA	NA			X
RQ-4 Triton Global Hawk (IHS Jane's 2014)	130.9' (39.8 m)	47.6' (14.5 m)	8,700 nm	28 hrs.	3,000 lbs.	X		X

Table 7. Selected survey conducted of current UAS platforms employed by the U.S. military.

Consider a comparison of the BQM-177A to the MQ-9 Reaper. The BQM-177A has a length of 17ft and a wingspan of 7ft which allows the baseline CVE to easily accommodate up to 60–70 platforms (Levine et al. 2013). The BQM-177A has a range of 500nm, endurance of 1.25hrs and an external payload capacity of 200lbs (Levine et al. 2013). The MQ-9 Reaper, on the other hand, has a significantly increased capability with

a range of 4,600nm, endurance of 32hrs, and an external payload capacity of 3,000lbs (IHS Jane's 2013). However, the MQ-9's size is also significantly larger with a length of over 36ft and wingspan of over 65ft (IHS Jane's 2013). Only one asset could fit across the 90ft width of the CVE flight-deck and it would only take six to fill up its 230ft x 90ft storage deck (Levine et al. 2013).

Another challenge to the Sea Vex concept is the reliance on wireless networks for UAS control. These networks are susceptible to electronic warfare such as jamming, spoofing, and hacking. A recent example of a state-of-the-art UAS system being captured by non-friendly state actors was when the RQ-170 drone was taken down while flying over Iran on 04 December 2011. It is speculated that Iranian agents were able to conduct an "electronic ambush" to jam the communications and GPS of the drone (Owano 2011). Wireless communications and navigation are susceptible to external forces and would require redundant communications and navigation systems to reduce the risk of external tampering.

Finally, the team determined that the reliance on waterborne-recovery of unmanned air vehicles, as part of the CVE CONOP set forth by the TSSE team, could present significant issues in a high-paced operational environment. A thorough analysis was conducted on this method as outlined below.

D. WATERBORNE-RECOVERY ANALYSIS OF BQM-TYPE UAVS

The CVE vessel is designed to launch UASs from four catapults on the front end of the vessel (Levine et al. 2013). Once the UAV mission is complete, the UAVs are designed to return to the ship conducting a water-landing in the vicinity of the ship. A helicopter or smaller surface vessel then recovers the UAV from the water and delivers it back to the CVE (Levine et al. 2013). Using waterborne recovery methods as a normal means to recover unmanned airborne assets is time consuming and could force the CVE to linger in a hostile threat environment. To explore waterborne recovery further, the team created a Monte Carlo simulation model.

a. Approach

A scenario was modeled in which multiple UASs return to the CVE after a mission and land in the water at a recovery point near the ship for retrieval. Each UAS landing event was treated as a random event, independent of any other factors in conjunction with the model. The team assumed a Circular Error Probability (CEP) and applied it in the random calculations of each UAS landing. CEP represents a radius from a target point where exactly half of the landings fall inside and half fall outside. The team used the simulated landing dispersal to determine how much area that the CVE would need to search in order to ensure the retrieval of 100% of the UASs dispersed around a landing point. Given the size of the search projected by the model, an estimate of the time it takes for the CVE to conduct a search and recovery of all the UASs was generated.

b. Assumptions

BQM-type airframes typically recover via flying to a recovery point, either over land or water, and employ a parachute for the final descent to land. A former BQM operator stated that the recovery could be done consistently within the first 1500 feet of a runway or about 0.25nm on an average day, about 0.125nm in terms of CEP. Given the parachute descent method, this accuracy varies based primarily on the wind speeds (Subject Matter Expert 2014).

In estimating the CEP for BQM recovery, the team considered the 0.25nm landing threshold and included plausible sources of dispersion that might affect the CEP given an operational maritime environment. First, it was assumed that GPS would not be reliable in the vicinity of the CVE vessel due to GPS denial tactics within an A2AD environment which would result in increased landing dispersion. It was also assumed that recovery would not be immediate and that the BQMs would spend a significant amount of time subject to environmental conditions such as wind and sea currents. From these environmental and operational assumptions, the team assumed doubling the CEP of 0.125nm to 0.25nm was reasonable.

For search and recovery, it was assumed that while the CVE travels along the search pattern path it will be able to see and recover BQMs within 0.25nm on either side

via a smaller surface vessel. It was also assumed that on average the recovery of a single vehicle would take about 30 minutes, although it has been reported that recovery time is highly variable and may take as few as 15 minutes or as long as 1.5 hours (Subject Matter Expert 2014). And finally, the time of this evolution includes launching the smaller recovery vessel, connecting to, towing and hauling the UAS back aboard the CVE vessel.

c. Model

A bivariate normal distribution was used to model 1,000 UAS landing events to determine the furthest probable extent of the area that a CVE would need to search during recovery operations. This then determined the size of the search area and subsequent travel distance that the CVE had to travel during search and recovery operations. The simulation results indicated that the search would need to be conducted in a 1.5nm x 1.5nm box, and that the CVE would have to travel a total distance of 7.5nm in order to search the entire area as seen in Figure 50.

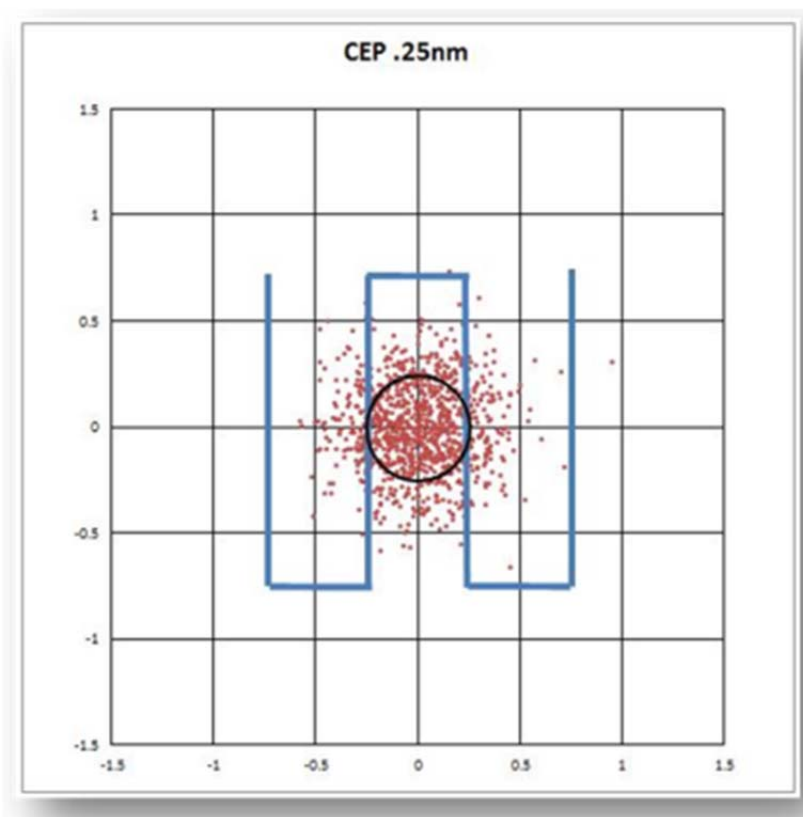


Figure 50. Simulation results for 1,000 landing events with a 0.25 nm CEP.

With the size of the search area determined, the recovery calculation was done assuming two different search speeds, five knots and 10 knots. The team looked at the recovery times required to gather three, four, and six UASs. These sets of UASs were multiplied by the estimated recovery time of 30 minutes for each UAS; and then the product of this (time to pick up all the UASs) was then added to the time for the CVE to travel the total search track which was 1.5hrs.

The results of the calculations from the 0.25nm CEP model are summarized below in Table 8.

		# of Assets			Average recovery time (hrs) for each asset
		3	4	6	
Speed (kts)	5	3hrs	3.5hrs	4.5hrs	0.85
	10	2.25hrs	2.75hrs	3.75hrs	0.67

Table 8. 0.25nm CEP recovery times for all UAS assets.

d. Implications

The results of the model imply that there is a significant amount of time that needs to be devoted to the recovery of UASs given waterborne-recovery methods. Recognizing that this does not include the time required for turnaround maintenance including maintenance inspections, saltwater rinsing, refueling, and reloading the UAS for another mission, these additional evolutions would easily add at least another 0.75 to one hour to the overall turnaround time of a vehicle.

Considering the results, the team has concluded that recovering aircraft via a waterborne recovery CONOP is not feasible in a high-tempo operational environment. Operating in this manner would prohibit the CVE from conducting efficient cyclic operations thus reducing critical sortie generation capability. It would also require the platform to remain in a small search area at very slow speeds for extended amounts of time during combat operations which is tactically infeasible. Therefore, it was concluded that use of the BQMs should be limited to single-use/one-way missions only.

E. SEA SCOUT DESIGN CONSIDERATIONS

Considering all of the advantages and disadvantages, the team's initial assessment was that the Sea Vex, as a high level concept, was a plausible alternative to consider going forward with. The concept could provide a cheaper more survivable naval air force structure that would lead to greater operational flexibility. However, key challenges needed to be addressed in the high level design of the system. Going forward with Sea Vex, the team focused its efforts on developing a design that would try to address the concept challenges while maintaining all of its advantages.

In order to stay on timeline and meet an Initial Operational Capability (IOC) in the 2025–2035 timeframe, the team developed the following design strategy.

- Develop the concept within an evolutionary acquisition strategy. This allows for priority capabilities to make it to the fleet in a timely manner by focusing on proven technology first and developing follow-on technologies in future increments.
- Concentrate efforts on developing a limited amount of naval air capability in the first increment rather than spreading resources thin to capture the capability of an entire CVW in the first iteration.
- Utilize to the maximum extent possible COTS/MOTS technology. This will help save in R&D expenses by leveraging current technologies that have been vetted through operational use as well as lower schedule risk by utilizing known and proven technologies.
- Design the UAS systems to do one or two missions exceptionally well versus designing a multi-role platform that marginally performs across several mission areas.

Considering the design strategy outlined above and keeping in line with the missions outlined in the project scoping statement, the team considered the development of four separate UAS mission sets: Surface Strike, Land Strike, Decoys and ISR. These mission sets allowed for the leverage of COTS/MOTS vehicles and high technology maturity level UAS technologies. Also, Strike and ISR relevance falls in line with the recommendations from the Air-Sea Battle report which highlights the importance of developing a robust ISR and Strike capability in order to deter aggressive acts from an enemy state (Tol et al. 2010). The team excluded the OCA and DCA mission sets from UAS design consideration for the Sea Vex concept due to the low maturity level of these

types of platforms, lack of current COTS/MOTS systems, and the large airframes likely required to provide effective capability.

The overall goal of this Sea Scout concept design, which is what it will be called from here on out, was to quickly field the initial capabilities, and deliver the additional capabilities in increments as UAS technology rapidly matures.

1. Scoping Considerations

Given the broad scope of alternatives considered in developing the Distributed Air Wing solution, it was necessary to determine to what depth the team could design and analyze the Sea Scout concept. The Sea Scout scoping kept in line with the study plus the following additional items that are delineated below.

a. CVE and UAS Platform Design Scope

In regard to the CVE platform, the design presented by the TSSE class project was utilized. Therefore, most aspects of the CVE design were considered out of scope. Certain aspects of the CVE design were brought into scope in cases where reconfiguration was deemed necessary to improve UAS air wing operations from the vessel. In this regard, slight modifications are recommended for the CVE design in relation to launch and recovery operations as well as deck space and storage space considerations. Otherwise, the overall size and general design of the hull and superstructure were not changed.

For UAS platforms, the study considered all avenues of the systems' design and functions to be in scope including UAS platform design, UAS mission CONOPS, as well as the design and CONOPS of the CVE launch and recovery apparatus.

b. UAS Mission Design Scope

The team initially considered every mission in the baseline Sea Vex concept mission-list as well as several missions outside of the list; however, given the desire to develop a concept that could be employed within years and not decades, it was determined that minimizing and prioritizing the capability of the first increment was prudent. As previously mentioned, the team concluded that making the UAS mission

design scope too broad would immediately place the potential acquisition program at high risk by spreading already sparse funding and resources over several complex technologies, therefore placing cost, schedule, and performance goals at risk.

F. SEA SCOUT ISR MISSION

In considering UAS capabilities and mission sets to employ from the Sea Scout concept, the ISR mission is at the forefront of possible alternatives because the mission provides military value on several levels. First, there is a vast amount of prior research and development already done that can be leveraged in the refinement of UAS technology. Therefore, the ability to use these commercial off the shelf (COTS) technologies and systems can drastically reduce the total acquisition cost of ISR mission-centric vehicles acquired by the naval services.

Second, ISR capability is extremely valuable and necessary to the fleet across all levels of warfare. On the strategic level, the UAS can be leveraged to provide persistent presence in a nonthreatening non-lethal manner. On both the strategic and operational level, ISR capability provides commanders with crucial information in regard to enemy movement and operations throughout the battle space. In an operational context specifically, the mobility of the UAS is especially valuable with the collection of information in a time-sensitive dynamic environment. Considering the tactical level, ISR configured UAS platforms can additionally provide for over-the-horizon (OTH) target detection, identification, and weapons grade positioning to cue OTH weapons systems.

Focusing further on the tactical level, the utilization of the ISR UAS as an early-warning and OTH targeting platform is of specific interest to the Navy in a war-at-sea context as it can provide surface-to-surface offensive and defensive functions. That said, the ISR mission presents a significant demand to the CVE magazine of assets in that, while operating in a combat environment, a constant and persistent presence is required along the threat sector to ensure target detection, identification and cueing. ISR assets used in this manner would have to remain airborne around the clock in order to ensure that the threat sector is covered.

Given that CVE has a finite amount of space with an initial concept threshold of about 60 BQM-74E Chukar-sized air vehicles, the primary purpose of the below analysis is to identify the number of ISR platforms required aboard the CVE to accomplish the OTH detection/targeting mission. The secondary purpose is to determine threshold values for the UAS technical parameters of speed, range, and endurance. Having an understanding of how much space is left after housing ISR platforms allows functional design teams to understand the capacity left for other UAS capabilities, and understanding the speed, range and endurance requirements will help understand the types of UAS platforms that can be considered for employment from CVE.

A third purpose of this analysis is to gain insights that help shape Sea Scout requirements and concept of operation (CONOP) within the context of not only UAS ISR platforms, but also Sea Scout as a system-of-systems.

1. Scenario

The exploration of Sea Scout ISR-capable UASs was done through a vignette within the U.S. and China Spratly Islands conflict scenario. The scenario involves a war-at-sea between the United States where U.S. forces are tasked with denying Chinese military vessels access to the Spratly Islands.

A single Sea Scout unit is attached to a Surface Action Group (SAG) to provide early-warning and surface-to-surface target identification and missile cueing. The SAG consists of four Aegis missile destroyers located about 130nm due West of Puerto Princessa, Palawan. The U.S. and PRC are engaged in full conflict and the rules of engagement allow for engagement of any vessel with a positive hostile identification. Given the abundance of merchant traffic in the area, positive hostile identification is met when the class and precise position of a vessel can be identified and correlated through a combination of any of the following sensors; optical, electro-optical, radar or forward looking infrared. The U.S. SAG has been ordered to maintain control of its present water space and engage any enemy contact that comes within range from its position off the shore of Palawan.

Intelligence has received indications that a PRC SAG containing an undisclosed number and type of vessels is steaming from a threat bearing of 360 degrees true. Based on further intelligence estimates and the time since last known position, the Composite Warfare Commander has defined a threat sector that covers a 90 degree arc from 315 degrees true, clockwise to 045 degrees true.

2. Concept of Operations

When considering ASCM employment from a surface vessel, the lack of an organic means to positively identify and provide over-the-horizon cueing is currently a gap that can potentially be filled by utilization of ISR-configured UASs.

The general concept of operations involves sending UAS vehicles equipped with sensors down range at a far enough distance to detect and identify enemy surface combatants prior to these combatants reaching their maximum weapons release range (a key assumption is that Blue forces have an anti-surface missile with maximum effective range greater than the adversary). Given a detection and positive identification, the UAS would then send precise targeting coordinates through a data link back to a missile launch platform. After the missile is launched, the UAS would continue to provide midcourse updates until the target is detected by the missile's seeker head.

The concept UAS is designed for the single purpose of detecting, identifying and relaying targeting information. It does not provide a means for weapons carry and delivery. Once deployed, the UAS is not utilized for secondary ISR missions, but maintains its primary mission function until recovered. It requires at least three UAS platforms to cover a search sector: one UAS on station performing the search, one UAS en route to relieve the current searcher and one UAS in a maintenance turnaround state onboard CVE. This assumes that the recovery and turnaround maintenance cycle can be done efficiently enough to allow the first UAS to relieve the third and thus continue the cycle indefinitely.

After being launched from the CVE platform, the UAS intercepts a maximum range flight profile. This profile begins with a maximum performance climb to cruising altitude. Once at cruise altitude, the throttle is set to achieve maximum range airspeed.

Next, the UAS performs fuel conserving minimum throttle descent to its search altitude between 8000ft AGL and 100ft AGL (depending on weather).

At the search distance, the UAS turns to place itself on a path perpendicular to the outbound path and conducts a back and forth barrier search at max endurance air speed.

During the barrier search, a cookie-cutter shaped detection threshold is applied to the radar sensor. If a new contact pierces the cookie-cutter circle by virtue of its path or the UAS's path, the UAS veers from its course and flies to within identification range of its optical sensors. Visual identification information is acquired and transmitted back to the UAS controller who identifies the vessel and declares it as friendly, hostile or unknown.

The sensors onboard consist of airborne sea search radar for detection and a Forward Looking Infrared (FLIR) targeting sensor capable of both visible and infrared sensing for target identification. Again, target identification is done through human-in-the-loop visual identification, but could be done by autonomous platform recognition through an onboard threat library in future systems.

With a hostile declaration, the coordinates are made available through a data link to the fire control computer onboard the missile platform and provides initial coordinates for a firing solution. After the missile is launched, it receives updates from the UAS via data link until the missile seeker-head detects and correlates the target.

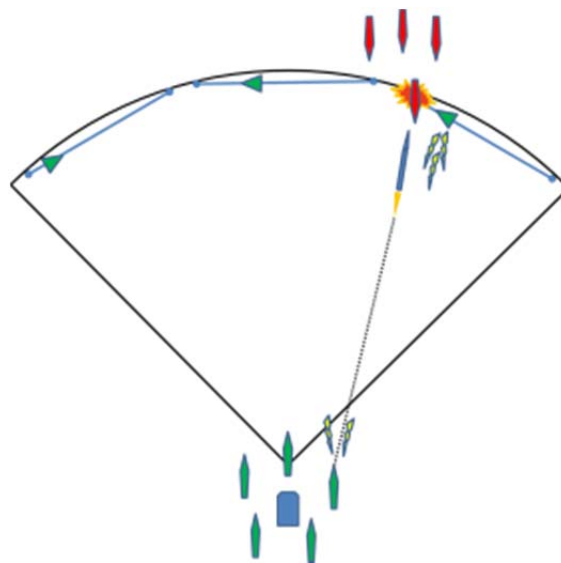


Figure 51. Visual depiction of ISR CONOP.

3. Analysis of BQM-74E Chukar III in the ISR CONOP

The baseline Sea Vex concept is designed around the utilization of the BQM-74E Chukar III as the primary UAS payload. Therefore, initial assessment was done to determine the feasibility of using the Chukar III for the Sea Scout ISR mission. The main assumption in using the Chukar III is that its 80lbs payload capability is utilized to support the array of ISR sensors (NAVAIR, PMA 208: Aerial Target and Decoy Systems).

A flight profile was calculated with data and methods from the BQM-74E NATOPS flight manual. The flight profile consisted of a maximum performance climb to 20,000ft MSL, level flight at max range cruise speed, followed by a descent to 4,000ft AGL for ISR operations. At the completion of ISR operations, the flight profile was repeated from climb to descent for recovery. It was calculated that the Chukar can drive out to a range of 100nm and remain on station long enough to do no more than three 20nm legs before having to recover (which equates to roughly 15 minutes time on station) (NAVAIR 2005).

This short range and time on-station makes the Chukar III infeasible for the mission on two accounts. First, assuming a 20min outbound flight, a 15min on-station time, a 20min return flight and a very optimistic 60min turnaround time, it would take seven additional vehicles launched at 15 minute intervals to continuously cover one 30nm search sector (20nm legs and a 10nm sensor reach with overlap). For a 90 degree threat sector with a 100nm radius, a total of five search sectors would be needed for a total of 40 air vehicles. Now, consider that the Chukar III utilizes a waterborne recovery method which is fairly time consuming. When recovery operations begin, five Chukars will need to be recovered from the water and returned to the CVE platform for turnaround maintenance every 15 minutes.

Second, the maximum radius of 100nm is insufficient considering threats that currently exist. For instance, take into account the SS-N-27B SIZZLER, a Russian surface-to-surface missile widely proliferated and utilized by potential threat nations. With the SIZZLER's published maximum range of 300km (~160nm) and conventional Blue force defensive doctrine of targeting launcher platforms well outside of the threat's

maximum range, a search radius of at least 180nm to 200nm is required (IHS Jane's 2012).

Taking into account the above analysis, the study did not specifically model the BQM-74E for the Sea Scout ISR mission and proceeded forward by modeling notional platforms to explore speed, range, endurance, search patterns and what effects these parameters had on probability of detection.

4. MANA Discrete Event Simulation of the ISR CONOP

The modeling tool Map Aware Non-uniform Automata (MANA) was utilized to explore probability of detection of UAS platforms conducting a barrier search in accordance with the above CONOP. MANA is a stochastic, discrete event simulation, agent-based cellular automata model with a wide range of functions that allows the very specific modeling of individual agent behavior. It was designed to be applied to a wide range of military applications and allows for the modeling of individual agent and squad behavior, weapons configurations, sensor configurations and situational awareness communications (McIntosh et al. 2007).

While the potential for MANA to intricately model behaviors is fairly broad, there were four different modeling attributes that made the program desirable for analyzing this particular ISR barrier search CONOP.

First, MANA provides the capability to model several different entities that can operate both individually and in squads. This allowed for the creation of the various types of vessels needed for the scenario which includes enemy and allied surface combatants, neutral shipping surface vessels and UAS searcher vehicles.

Another important attribute is the ability to model sensors. MANA specifically allows for both detection and identification ranges which enables the modeling of both UAS sensors required in the barrier search CONOP; surface search radars (detect) and optical sensors (identify).

The third important attribute is the ability to model communication links where entities can provide situational awareness to other entities. This feature allowed for the

over-the-horizon targeting aspect of the CONOP to be modeled with the UAS platforms transmitting situational awareness data back to the shooter platform.

Finally, MANA is capable of modeling weapons which is critical in combat models. Specifically, the probability of hit (P_{hit}) can be modeled to include a decreased probability of hit with increased range.

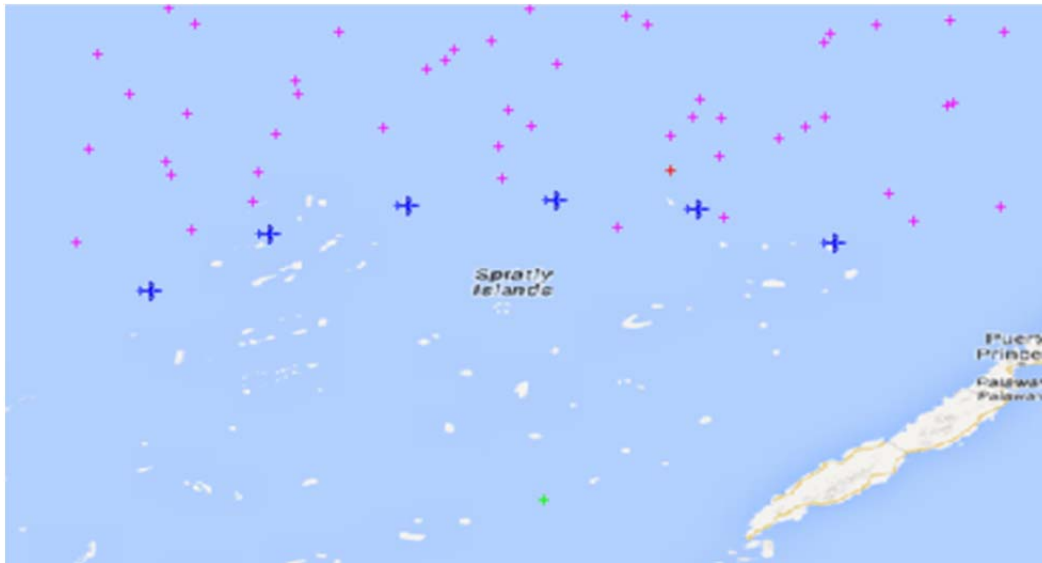


Figure 52. MANA screen shot depicting barrier search model.

a. MANA UAS ISR Searcher Mission: Modeling Specifics

The MANA model within this study was built to focus on and explore the search and identification aspect of the ISR barrier search UAS CONOP and does not incorporate cueing to a missile shooter (this facet of the CONOP will be explored in future versions of the model). The aim of the ISR barrier search model is to identify the best combination of UAS numbers, barrier search leg lengths, and search speeds to serve as a basis for requirements' thresholds. The later model will build upon the ISR model and add the surface shooter element with weapons exchanges between the two surface forces.

The MANA search and identification model utilizes four separate entities. The first type of entity, are the UAS searcher entities that are distributed along a range arc within a 90 degree threat sector. The barrier search path is essentially a chord drawn between two points on the arc, and its length is determined by dividing the arc equally

among the number of searchers. The searcher flies back and forth between two waypoints that intersect the arc. Search endpoints are spaced 10nm between UAS searcher search paths to allow for overlap of UAS sensor identification range to ensure no gaps between searchers. While conducting its search, if a UAS detects a contact, it can veer up to ~5nm off of course to attempt identification. When a contact is made, the entity slows to half of its search speed to account for maneuvering and orbiting that would be required to visually identify a target in a real world mission. Once an entity is identified or the target moves out of contact range, the searcher returns to its normal search speed and continues on a straight path towards its waypoint until it comes into contact with another unknown contact.

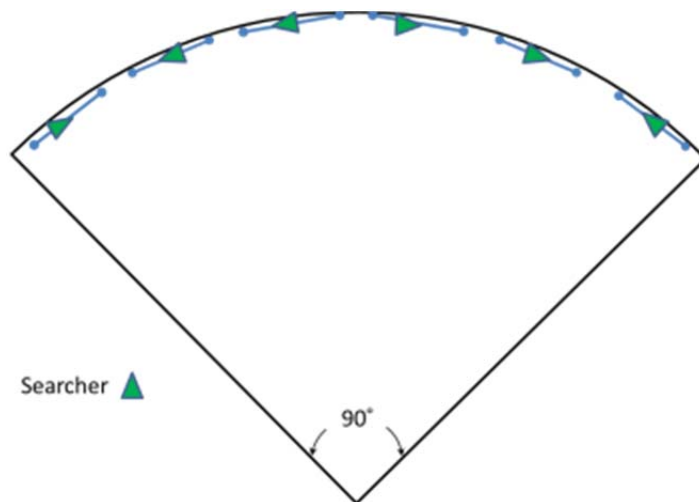


Figure 53. Depiction of six searcher path configuration.

The second entity is a single unit that marks the CVE position. The CVE unit is merely a place-marker to give a visual reference as to where the UAS searchers would originate from as well as the threat sector origin.

The third entity in the search and identification model is a single Red unit. On each run, the Red unit starts randomly between the end points of the 90 degree arc just outside of the search range. From its starting position, it makes a pure pursuit course towards the CVE platform. In other words, the red unit does not attempt a flanking maneuver to bypass the barrier search.

The fourth and final entity type, are the merchant shipping vessels which appear and maneuver randomly at a density of ten vessels per 100nm x 100nm section of water space. These entities represent “white shipping” that can be identified optically at detection range as a warship-sized contact. There are no entities that represent small skiffs or fishing vessels. The assumption here is that, at radar contact range, optical resolution is good enough to distinguish between a small fishing vessel and a warship-sized vessel. However, a closer approach is needed to tell for certain whether a warship-sized vessel is actually a warship. Figure 54 depicts the search and identification model entities and their basic layout.

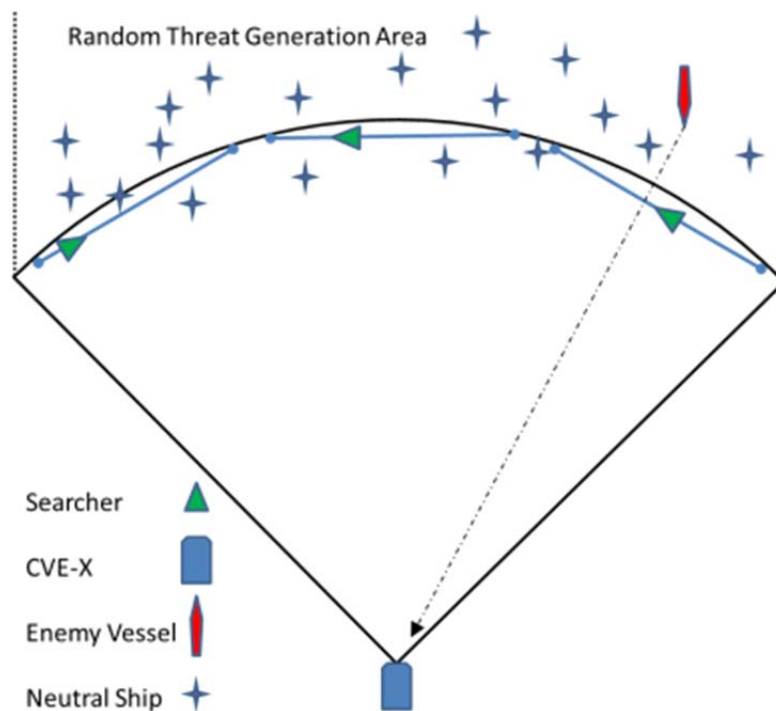


Figure 54. Depiction of basic MANA model layout (three searcher configuration without traffic).

b. MANA Modeling Assumptions

Below is a summary of the assumptions of the barrier search model:

- A single UAS model entity represents the multiple platforms required to continuously support a search sector.

- The model does not explicitly model the launch and recovery of multiple UAS vehicles.
- Sensors have a detection range of 15nm and an identification range of 7nm.
- Entities will veer off of course up to ~5nm to prosecute a contact. If veering off course does not bring the contact into identification range, the entity will continue on to its waypoint. This was necessary in MANA to keep a searcher entity from veering excessively off course when randomly placed vessels were spaced close together.
- Line-of-sight communications between searcher and shooter platforms are maintained throughout the search.
- Detection is 100% accurate.
- Identification is 100% accurate.
- An actual enemy SAG would have several ships; however, a single enemy vessel was used in the model for the purpose of easily quantifying and comparing the MANA model data to the analytic barrier search model.
- Enemy combatants travel at 20kts to remain inconspicuous in their approach.
- Searcher platforms reduce speed to 50% of their search speed when in contact with a surface contact until it is identified.
- The threat sector search radius is 200nm in order to give a 40nm buffer zone prior to the SIZZLER's 160nm maximum launch range.

c. Design of Experiment

In barrier search theory, barrier lengths and the speeds of both the searcher and targets are independent variables. Therefore, the design of experiment varies the number of UASs, which determines the barrier lengths and the searcher speeds. The searcher speeds ranged from 300kts, representative of jet-powered UASs, to 50kts which represents speeds of smaller scale propeller-driven vehicles. Target speed was fixed at 20kts in accordance with the assumption above. A third aspect of the design compared searches with traffic and without traffic to determine if there would be a significant difference in detection when the searcher is interrupted along its search path while identifying the merchant vessels. The specific parameters used in the design of experiment (DOE) are given below in Table 9.

Search Speed	Number of Searchers	Shipping Vessels
300kts	6 (45nm legs)	Yes
200kts	4 (70nm legs)	No
100kts	3 (90nm legs)	
50kts		

Table 9. Design of Experiment summary.

The model was replicated 100 times for each case. As suspected, higher search speeds and shorter search legs resulted in practically assured detection. Across all “Number-of-Searcher categories,” a speed of 150kts and above resulted in a Pd of .99 or better. In the six and four searcher categories, speeds as low as 100kts attained a Pd of .98 or better.

Shipping traffic did not greatly affect Pd given short search legs and speeds above 100kts as seen in the case of six-searcher and four-searcher models.

In the six-searcher model, where Pd falls off from 1.0, there is only a .03 difference in Pd between the Traffic and No Traffic cases. Given a 95% confidence interval of .81 – .94 for No Traffic; and .77 – .91 with Traffic, there is no significant difference in regard to the six-searcher model.

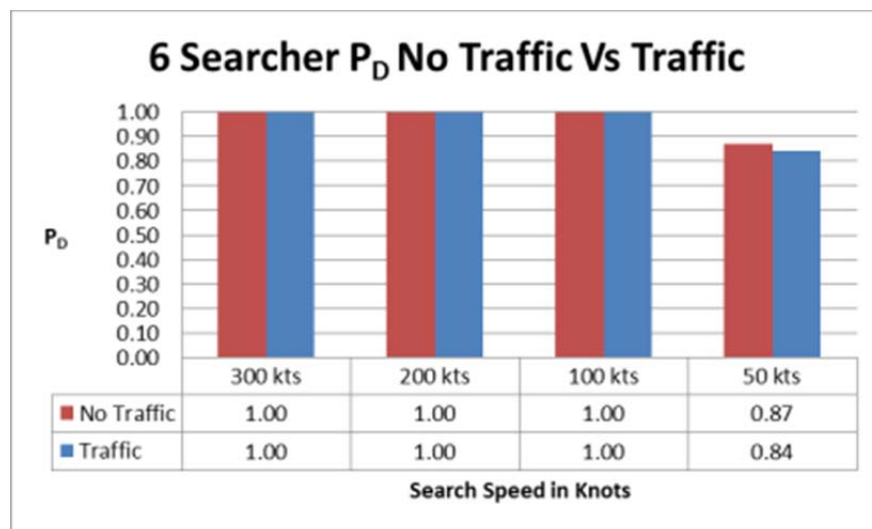


Figure 55. Six-searcher traffic/no traffic comparison.

In the four-searcher model, there is a .04 difference between the Traffic and No Traffic cases. With 95% confidence intervals of .64 – .81 for the No Traffic case; and .60 – .78 for the Traffic case, there is no significant difference. For these calculations, the Agresti-Coull *score confidence interval* method for Binomial Confidence intervals was utilized for all CIs (Agresti and Coull 1998).

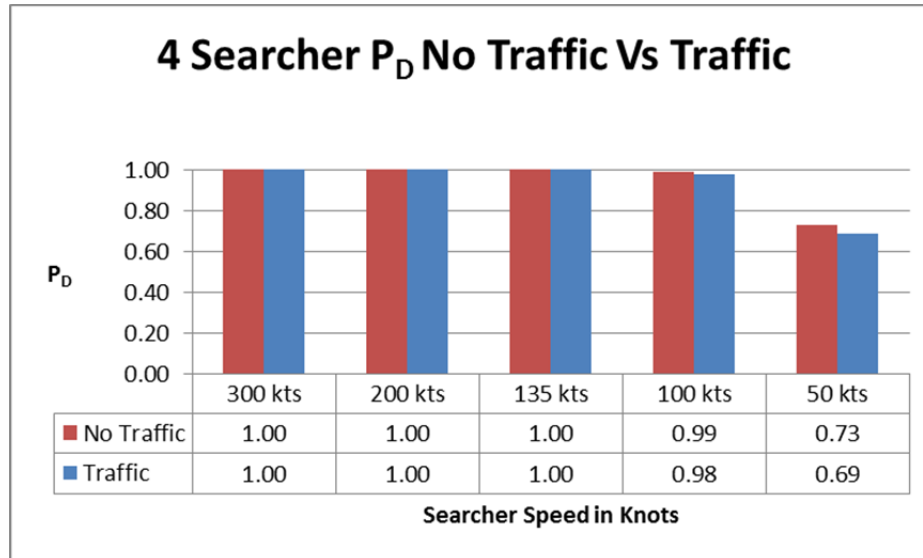


Figure 56. Four-searcher traffic/no traffic comparison.

In the three-searcher model, only the 50kt searcher speed case shows a significant difference between No Traffic and Traffic cases; with a No Traffic 95% confidence interval of .52 - .70 and a Traffic confidence interval of .30 - .49.

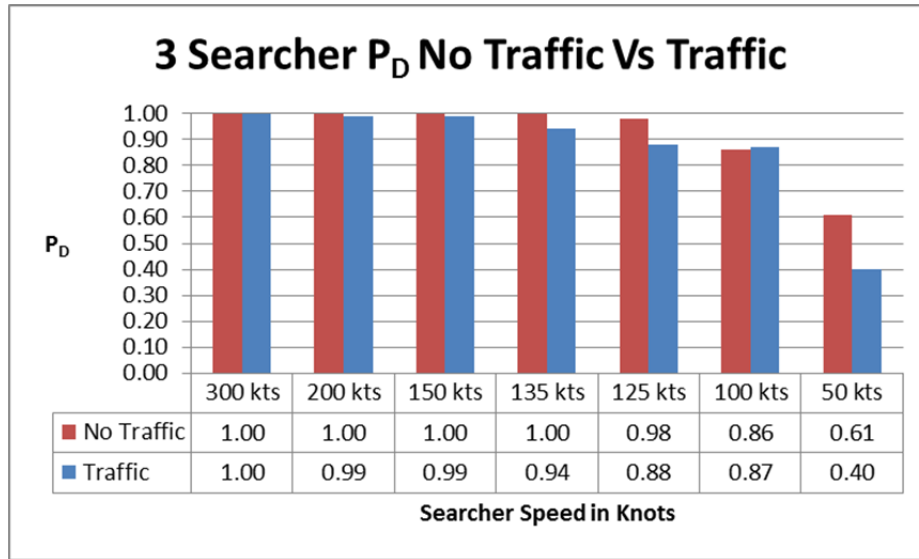


Figure 57. Three-searcher traffic/no traffic comparison.

Given the above comparisons, it can be concluded that, within the constraints of this model, shipping traffic only makes a significant difference when search speed is slow (below 100kts) and search legs are long (over 70nm).

Since having three searchers is the most advantageous in regard to space and resources aboard the CVE platform, confidence intervals were used to compare search speed results of the three-searcher model to determine a design threshold for speed. Figure 58 depicts this comparison.



Figure 58. Three-searcher case comparison of P_D .

With the desire to have assured detection, an acceptable threshold for the searcher UAS in regard to speed would be the slowest search speed that assures detection. Allowing the slowest search speeds to be considered gives a wider range of solution alternatives by including the possibility of using both jet and propeller air vehicles. This threshold essentially marks the no-lower-than point where speed can be traded for range and endurance in the use of propulsion methods other than jet engines.

From Figure 58. it can be seen that 135kts is where assured detection begins to drop off, although with overlapping confidence intervals to either side. Moving further to the left, 125kts and 100kts both have confidence intervals outside of the 150kts data point. Therefore, based on this model, the speed threshold should be set at the very minimum to 135kts.

5. Search Theory Analytic Model

Probability of detection can be fairly easily calculated with an analytic barrier search model from search theory. The equation below was utilized to provide a back-of-the-envelope calculation to compare with the stochastic MANA model. It does not account for the searcher veering off path or slowing its speed in order to identify a contact.

Figure 59. and accompanying equations represent an approach to deriving the barrier search equation from a target stationary perspective as presented by Professor James Eagle of the Naval Postgraduate School which was adapted from A.R. Washburn, *Search and Detection*, 4th Ed., Institute of Operations Research and the Management Sciences, 2002, Section 1.3 (Eagle 2013).

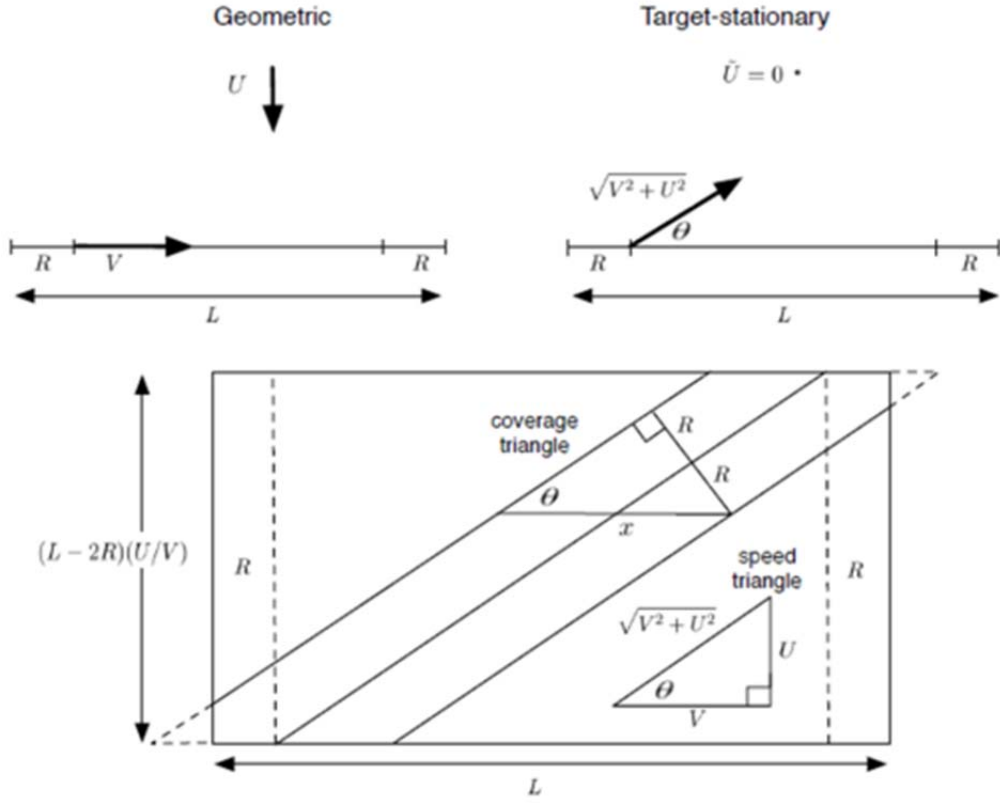


Figure 59. Barrier search geometry (from Eagle 2013).

Referencing Figure 59 the probability of detection given one transit across the path is:

$$Pd \approx \frac{\text{Area of Parallelogram}}{\text{Area of Search}}$$

Therefore:

$$Pd \approx \frac{x(L - 2R)(U/V)}{L(L - 2R)(U/V)} = \frac{x}{L}$$

Since the coverage triangle and the speed triangle are similar:

$$\frac{x}{2R} = \frac{\sqrt{U^2 + V^2}}{U}$$

So,

$$x = 2R\sqrt{1 + (U/V)^2}$$

and,

$$Pd \approx \frac{x}{L} = \min \left\{ 1, \frac{2R}{L} \left(\sqrt{1 + (U/V)^2} \right) \right\}$$

Since the CONOP applies identical searches across a straight line in each sector and the entire arc is covered by the searchers, the probability of detection across a single search path is equal to the probability of detection across the entire arc. In this case, the numerator and denominator are both multiplied by the number of searchers.

The above calculation was applied to each No Traffic test case. The sensor was given a radius of 10nm vice 15nm to account for the behavior in MANA that requires a target to have a closest point of approach of ~10nm from its search path before the searcher will veer away from its course and identify the target.

Probability of detection calculation results are presented below with percent differences. The barrier search equation was entered as the accepted value for the calculation. A negative value signifies that the MANA result gives a lower value than the analytic equation. A positive value signifies that the MANA result gives a higher value.

3 Searcher	300kts	200kts	150kts	135kts	125kts	100kts	50kts
MANA	1.00	1.00	1.00	1.00	0.98	0.86	0.61
Equation	1.00	1.00	1.00	1.00	1.00	0.93	0.49
% Dif.	0	0	0	0	-.02	-0.08	0.24

Table 10. Pd % differences between three searcher models.

4 Searcher	300kts	200kts	135kts	100kts	50kts
MANA	1.00	1.00	1.00	0.99	0.73
Equation	1.00	1.00	1.00	1.00	0.67
% Dif.	0	0	0	-0.01	0.09

Table 11. Pd % differences between four searcher models.

6 Searcher	300kts	200kts	100kts	50kts
MANA	1.00	1.00	1.00	0.87
Equation	1.00	1.00	1.00	0.49
% Dif.	0	0	0	0.77

Table 12. Pd % differences between six searcher models.

The analytic search theory calculation proved to be slightly more optimistic than the MANA values in the 100kts to 135kts range. Perhaps one reason is the behavior exhibited in MANA where a searcher is pulled off of its path and slows to investigate the target, especially if the identification of the target in the MANA model requires the searcher to veer too far off course. Therefore, on rare occasion, there would be a drop of contact as the searcher continues along the waypoint.

At the 50kts test point the opposite occurred. MANA presented more optimistic numbers, and in the case of the six-searcher model shows a 77% difference between the analytic and stochastic models. It was unclear why this result may have happened and will require further investigation. While there is disparity between the models at the slower search speeds, both models suggest that 135kts or better is a safe lower bound for assured detection.

6. Implications from Both Models

Based on both previous analysis models, the BQM-74E is not a viable alternative for use as an ISR UAS platform in the Sea Scout concept during the South China Sea Scenario. It has neither the range nor endurance to effectively search at a range that would allow for the targeting of a surface-to-surface threat prior to reaching its maximum range of employment. Even if its range were significantly extended, the waterborne recovery aspect of the vehicle prevents it from being viable for cyclic operations.

A three-searcher CONOP is the most desirable as it eases support requirements and allows a larger number of vehicles in the CVE magazine to be utilized in missions other than ISR. Using this CONOP also allows for a speed design threshold as low as

135 kts, which opens up the use of other-than-jet options such as tilt-rotor, rotary-wing, and propeller-driven air vehicles.

In the case of rotary-wing and tilt-rotor aircraft, these platforms were thoroughly examined to explore the benefits of their capability to launch and recover without the use of catapults, arresting gear and waterborne methods. It was determined that utilization of these types of vehicles negate the costly requirement of installing catapults on a CVE and save the time, money and manpower required in the waterborne recovery method of the baseline concept. By eliminating catapults from the ship design the overall acquisition cost would be decreased by \$318M (FY14) (Levine et al. 2013).

Considering the results of this study, the following recommendations are submitted for consideration in the requirements for the Sea Scout ISR platform.

- Utilize a search speed threshold (i.e., minimum) of 135kts
- Utilize a search CONOP of three sectors covering 90 degrees, with a radius of 200nm, and 90nm perpendicular legs.

Based on this CONOP, the threshold for range and endurance should allow for a launch, recovery and turnaround cycle utilizing no more than three vehicles per search sector, i.e., one vehicle on-station, one airborne to relieve and one undergoing turnaround maintenance. Assuming recovery and turnaround takes no longer than 1.5 hours, a relief would be launched every 2.25 hour, take 1.5 hours to transit outbound, remain on station for 2.25 hours, and take another 1.5 hours to return to base. This equates to a range threshold of 710nm and an endurance threshold of 5.25 hours. The time schedule in Table 13 outlines this concept in detail for three air vehicles over one cycle.

Schedule (Hrs.)			
	AC1	AC2	AC3
Launch	0	2.25	4.50
Arrive Cap	1.50	3.75	6.00
Leave Cap	3.75	6.00	8.25
Land	5.25	7.50	9.75
Launch	6.75	9.00	11.25
Time Cost (Hrs.)			
Outbound			1.50
On-Station			2.25
Inbound			1.50
Turnaround			1.5

Table 13. Summary of cyclic time schedule.

7. ISR UAS Platform Selection

Given the above analysis, the team focused UAS design efforts on exploring various Vertical Takeoff and Landing (VTOL) capable options that might fit the ISR searcher threshold values. The current inventory of U.S. operational VTOL UAS platforms is quite small compared to fixed winged vehicles, so the scope was expanded to include designs outside of the United States inventory. The VTOL UAS market survey is summarized below in Table 14. and represents the most capable systems found during the search in regard to speed, range, endurance and payload capacity.

Company	IAI (Israel)	Saab (Sweden)	Unmanned Systems Group (Swiss + Sweden)	Bell Helicopter (US)	Northrop Grumman (US)	Boeing (US)
Model	NRUAV	Skeldar V-200	ATRO-X	Eagle Eye	Fire Scout (MQ-8B)	Hummingbird
Length	12.84 m	17.1 ft. (5.2 m)	4.3 m (14 ft.)	~18 ft. (5.46 m)	30.03 ft. (9.2 m)	35 ft.
Rotary Diameter/ Wingspan	11.02 m	Length includes rotary diameter	6.20m (20 ft.)	9.6 ft. (2.9 m)	27.50 ft. (8.4 m)	6 ft.
Height	2.97 m	4.3 ft. (1.3 m)	2.1 m (6.8 ft.)	~ 5.8 ft. (1.74 m)	9.71 ft. (2.9 m)	9.71 ft.
Max. Takeoff Weight	2,200 kg	518 lbs. (235 kg)	350 kg (771 lbs.)	2,250 lbs. (1,020 kg)	3,150 lbs. (1,428.8 kg)	5,500 lbs. - 6,000lbs
Max. Payload Weight	220 kg	88 lbs. (40 kg)	120 kg (264 lbs.)	200 lbs. (90 kg)	600 lbs.	2,500 lbs.
Range	150 km	> 100 km	200 km (108 nm)	110 nm (200 LOS km)	110 nm (200 LOS km)	2,250+ nm
Endurance	6 hrs.	6 hrs.	> 2.5+ hrs.	~ 4 hrs.	8+ hrs.	20+ hrs. (@15,000 ft.)
Max. Speed	100 kts	140 km/h/75 kts	200 km/h (124 mph)	210 kts	135+ kts	222 kts
Cruise Speed	60 kts		120 km/h (77 mph)	Cruise 0 - 200kts	115+ kts	165 kts
Altitude	11,500 ft. (3.5 km)	> 11,500 ft. (3.5 km)	11,500 ft. (3.5 km)	20,000 ft. (6.1 km)	20,000 ft. (6.1 km)	20,000 ft. (6.1 km)
Source	(Israeli Aerospace Industries 2014)	(Saab Group 2014)	(Unmanned Systems Group 2014)	(IHS Jane's 2011)	(IHS Jane's 2014), (Northrop Grumman 2014))	(Boeing 2014), (IHS Jane's 2013)

Table 14. VTOL market survey summary.

In the survey, the Boeing A160 Hummingbird was the only alternative that met every threshold value determined by the ISR CONOP analysis in terms of range, speed and endurance. Not only did it meet thresholds; it greatly exceeded them. That said, there are risks associated with the design, as the platform is technically still a developmental system. Also, it should be acknowledged that the technology has had its challenges, which have been exacerbated by cuts in the U.S. defense budget as outlined in the platform summary below. However, considering its capability potential, the significant amount of development invested to date, and the timeline in which the system has to

come online, the team concluded that it was the most plausible airframe to utilize for the Sea Scout system's fielding timeframe goal of 2025–2035.

a. A160 Hummingbird

The A160 Hummingbird began development in 1998 by the Frontier Aircraft Company, and became a Boeing project after the company was purchased in May 2004 (Golightly 2004). The design was based on DARPA requirements for a low observability, rotary-winged surveillance UAV, with flight endurance up to 48 hours (IHS Jane's 2013). The aircraft underwent several years of technological development and flight testing with significant achievements in capability to include an 18 hour, 41 minute and 28 second continuous flight in May 2008, which at that time was deemed a world record for an autonomously controlled vehicle in its size-class (IHS Jane's 2013). By 2009 the platform had achieved significant enough capability to gain the interest of U.S. Special Operations Command (SOCOM). IHS Jane's sources report that SOCOM began the process to acquire 10 airframes in October 2009, and a year later Boeing funded the production of 21 A160 airframes (IHS Jane's 2013).

Between 2010 and 2012 the platform underwent substantial developmental and operational testing with SOCOM and the U.S. Army (IHS Jane's 2013). The Marine Corps also considered the platform in its Cargo Unmanned Aerial System program where the platform successfully autonomously delivered two sling loads of 1,250lbs in two 150nm round trips, meeting all program thresholds (McHale 2010). The Marine Corps passed on the Hummingbird likely in favor of the competing system Lockheed Martin's K-Max, which has a 3.5ton single payload capacity (Roach 2011). (Note: The K-Max was not considered for Sea Vex due to its large size.)

Significant development of the platform continued within the U.S. military until April of 2012 when a single platform crashed while undergoing a flight test in Victorville, California. It was the third crash over the two-year time frame. Two months later, the U.S. Army issued a "stop work" notice (IHS Jane's 2013), and in December of 2012 the program was discontinued when budget constraints forced the U.S. Army to abandon the pursuit of a rotary-winged UAV (Magnuson 2012).

As of February 2013, IHS Jane's reports that Boeing continues to promote the Hummingbird (IHS Jane's 2013), and it is still marketed on the official Boeing website at the time of this report (Boeing 2014). It is unclear whether or not SOCOM still utilizes the platform.

In spite of the program's recent hiatus, the platform has developed a significant amount of mission capability to include ISR, Direct Attack, Communications Relay and Precision Resupply applications. A summary of key operational attributes are summarized below (IHS Jane's 2013):

- Autonomous operation.
- Various EO/IR Sensor integration schemes
- Foliage penetrating Reconnaissance, Surveillance, Tracking and Engagement Radar integration (FORESTER)
- Vehicle Dismount and Exploitation Radar (VADER)
- Adaptive Conformal Electronic scanning array Radar (AACER)
- LIDAR capability
- SIGINT capability
- SATCOM capability
- Up to eight x Hellfire-type air-to-surface missiles



Figure 60. A160 Hummingbird (from Boeing n.d.).

8. ISR UAS Platform Integrations with CVE

A spatial analysis was conducted in regard to the feasibility of embarking the A160 Hummingbird aboard the TSSE CVE ship design. It was determined that accommodating the UAS platform within the vessel only required slight modification to the original design as seen in Figure 61 and described further below.

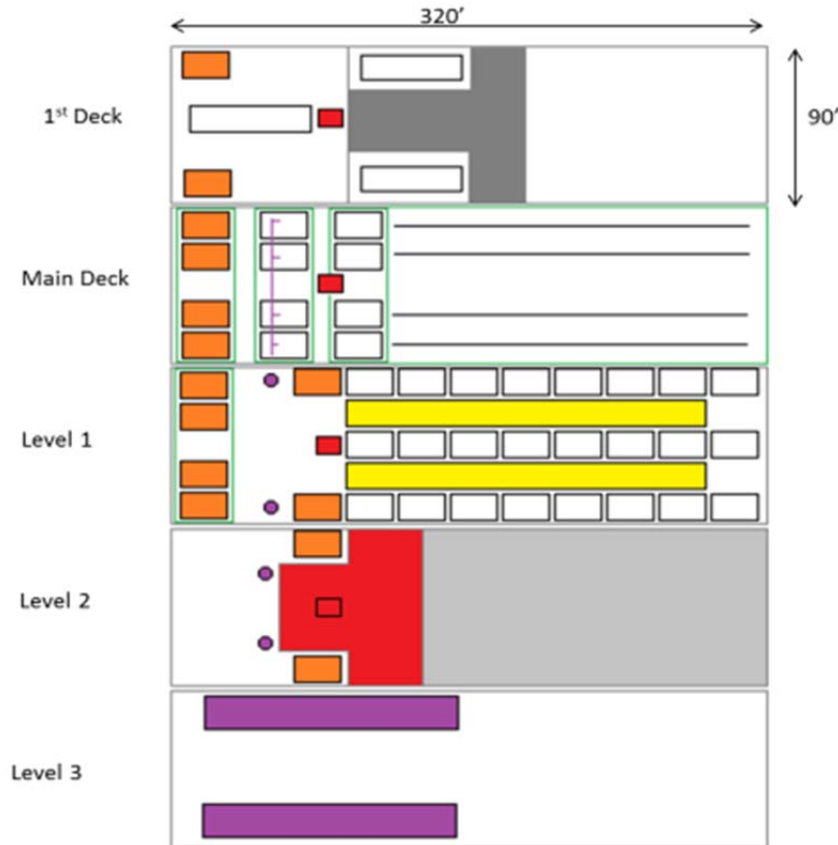


Figure 61. TSSE CVE deck layout (from Levine et al. 2013).

To accommodate the Hummingbird's dimensions, elevators would need to be enlarged on Level One, Main Deck, and First Deck. A dimension of 40 ft. x 40 ft. would allow for either two vehicles with rotors folded, or one vehicle with rotors configured for flight to fit on each elevator.

Level One would need to be reconfigured as an open bay design similar to the hangar deck of an aircraft carrier. It was determined that this deck could easily hold 15

vehicles with the rotors folded and still have plenty of space for maintenance and movement.

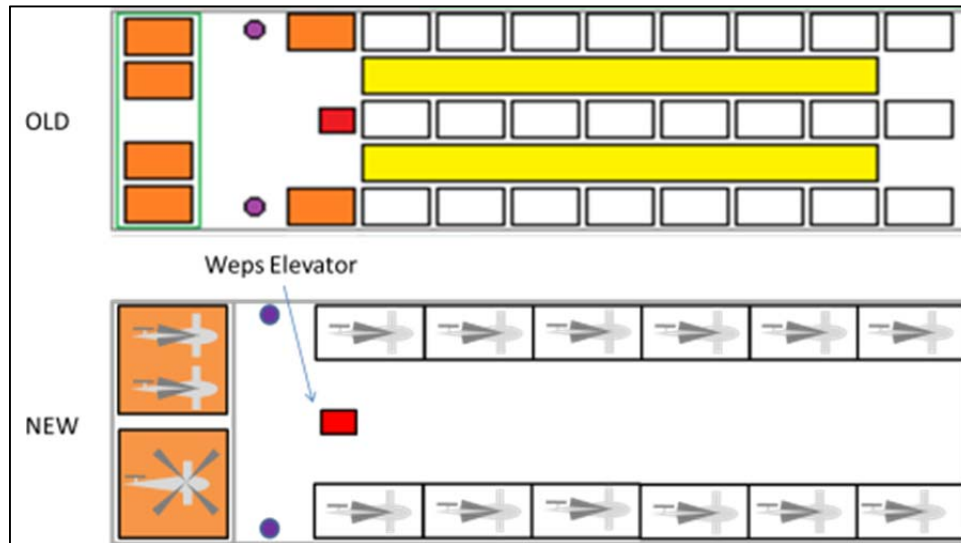


Figure 62. Old vs. New Hangar Deck configuration (from Levine et al. 2013).

The Main Deck or Forward Flight Deck would also require some minor modifications. In the original design, the area immediately underneath the super structure is cluttered with several refueling stations and racks to accommodate BQMs. To accommodate Hummingbirds, the space would again need to be opened up in the same manner as the hangar deck by removing the racks and placing refueling points against the port and starboard bulkheads. This reconfiguration would allow for two landing spots in front of the superstructure and four to six airframes with rotors spread underneath the superstructure.

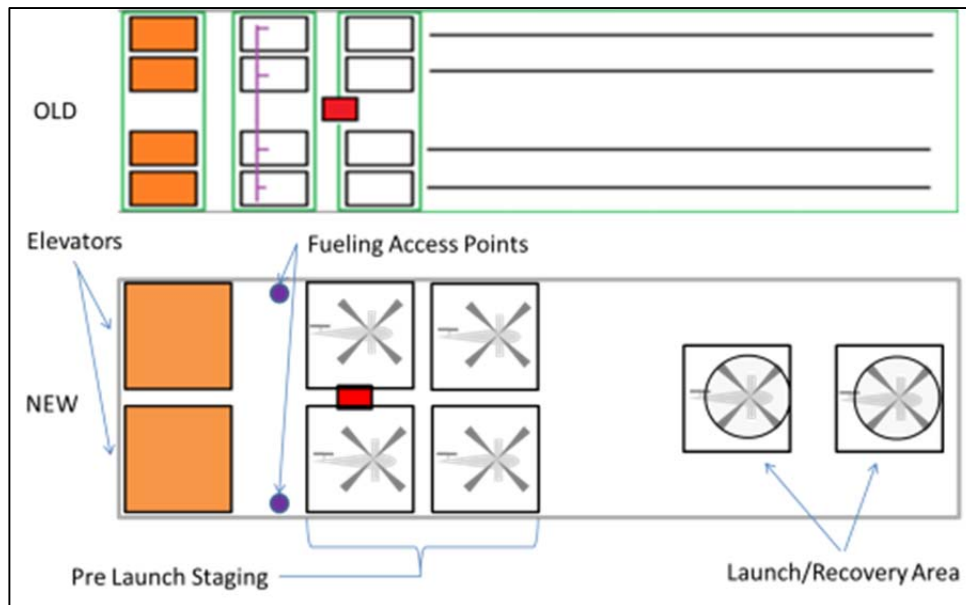


Figure 63. Old vs. New Main Deck configuration (from Levine et al. 2013).

Extending elevators up to the First Deck would allow UAS launch and recovery to be conducted from the helicopter deck as well allowing up to three Hummingbirds to launch and/or recover simultaneously.

The team assessed that this reconfiguration allows for enough space to embark at least 21 Hummingbirds aboard CVE and still have enough room to conduct maintenance operations and allow for system growth. Considering the ISR CONOP, this amount of aircraft would provide 180 degrees of coverage out to 200+ nm.

G. SEA SCOUT STRIKE AND DECOY MISSIONS

Traditional CVW assets bring a tremendous amount of Strike capability into the Commander's battle plan due to their significant payloads and ability to generate a high volume of sorties. Therefore, if a CVW is denied access into a theater, a substantial amount of the Combatant Commander's strike power is cut off. The Sea Vex concept presents an opportunity to ensure that a significant amount of strike capability can operate under the A2AD umbrella and service these targets when traditional assets are denied the ability.

The idea of developing a UAS for use as a decoy was considered in tandem with the strike mission because their use is envisioned as a way to increase the effectiveness of

the Strike platforms. There are two manners in which this effect might be accomplished. First, the decoys could serve in a military deception tactic. An example of using them in this manner would be to feint an attack from single or multiple directions in order to disguise the actual direction of the incoming strike package. The other way that decoys could be used is to employ them in concert with Strike assets in a way that saturates enemy defenses and increases the likelihood that the Strike assets will reach their intended targets unscathed. In this study, the latter was explored with quantitative analysis.

1. Strike and Decoy Platform Consideration

In regard to the type of Strike platform to utilize onboard the CVE, the team considered two CONOPS. The first CONOP involved the utilization of a reusable platform that could launch from the CVE, carry a payload of ordnance, acquire the target, deliver its ordnance, and recover back aboard the CVE. The other concept that was considered involved utilizing a single-use disposable platform where the air vehicle would launch from CVE on a one-way mission.

In exploring the reusable-vehicle CONOP, the team first considered BQM platforms, but immediately discarded them as a viable option for the same reasons they were discarded from the ISR mission. Their range, endurance, limited payload capability, and waterborne-recovery constraint made their use infeasible. However, BQM platforms were kept in consideration to be utilized as one-way Strike platforms.

Next, COTS/MOTS systems were considered. Several fixed-wing vehicles showed promise in terms of capability. However, significant Strike capability was by and large attributed to large airframe designs, which is not conducive to the limited space onboard a CVE. Also, their utilization would require major redesign of the CVE to accommodate recovery operations. In addition to taking up precious space onboard the CVE, fixed-wing vehicles would also require adding some type of arresting system resulting in the need to expand the length of the ship. The team surmised that if the CVE design was increased in size to accommodate these larger fixed-wing platforms, it would quickly grow to the size of a CVL and fail to preserve the advantages of cost and overall size.

The team again turned to the VTOL designs to capitalize on their small launch and recovery footprint. In this class of vehicles, the MQ-8 Fire Scout and A160 Hummingbird were considered. Table 15 outlines a comparison of their capabilities.

Company	Boeing (US)	Northrop Grumman (US)
Model	Hummingbird	Fire Scout (MQ-8B)
Length	35 ft.	30.03 ft. (9.2 m)
Rotary diameter/ Wingspan	6 ft.	27.50 ft. (8.4 m)
Height		9.71 ft. (2.9 m)
Max. Takeoff Weight	5,500 lbs. - 6,000lbs	3,150 lbs
Max. Payload Weight	2,500 lbs.	600 lbs
Range	2,250+ nm	110 nm
Endurance	20+ hrs. (@15,000 ft.)	8+ hrs.
Max. Speed	222 kts	115+ kts
Cruise Speed	165 kts	
Altitude	20,000 ft. (6.1 km)	20,000 ft. (6.1 km)
Source	(Boeing 2014), (IHS Jane's 2013)	(IHS Jane's 2014), (Northrop Grumman 2014)

Table 15. Capability Comparison of COTS VTOL UAS platforms.

While VTOL aircraft can fit the ISR mission very readily, their use as a Strike asset appeared to be limited. Fire Scout did show promise as a plausible candidate given its proven capability in the maritime operational environment; however, its payload capacity is fairly low at 600 lbs. Also, the Fire Scout has a very limited combat radius of 110nm. This short range would require the CVE to drive well into the weapons ranges of both surface and land targets which is tactically infeasible.

In regard to the A160 Hummingbird platform, the team determined that it had a significant enough range, endurance, and payload capability to be considered for the Strike mission. However, in comparison to jet and rocket powered alternatives, its maximum speed of 225 knots sacrifices valuable transit time along with the ability to quickly put ordnance on time-sensitive targets. Their consideration for the Strike mission was tabled as the team moved on to explore one-way Strike vehicle CONOPS and platforms.

As mentioned earlier, BQM-type air vehicles were considered as plausible options for use as Strike platforms in a one-way mission CONOP. However, the team determined that a considerable amount of reengineering would be needed to apply kinetic capability to the platform. At a minimum, it would need to be fitted with a warhead and fusing system. The BQM platform could use its current GPS navigation system for terminal guidance; however, if the platform were to be utilized against mobile targets such as naval vessels or land vehicles, it would also require developing some type of seeker-head. Considering the current unit cost of BQM platforms, which is between \$340K and \$890K (Levine et al. 2013), the cost of modifying them to deliver kinetics would likely push the unit cost into the price range of sea-launched missile systems that already exist such as the Tomahawk Land Attack Missile (TLAM) which costs between \$751K (FY14) and \$1.54M (FY14) depending on the variant (U.S. Navy 2014) (National Priorities Project 2013). At this point, it was determined that modification of the BQM into a Strike platform was not a viable option. However, the team noted that the BQM design is very well suited for the decoy mission and decided to utilize the platform if decoys proved useful in the analysis.

Attention was next directed to sea-launched attack missiles to explore the feasibility of their use to fill the Strike role in the Sea Scout concept. The team immediately considered two missile systems; the TLAM and the Long Range Anti-ship Missile (LRASM).



Figure 64. Tomahawk Land Attack Missile (from Raytheon 2014).

TLAM is a well-developed Strike missile system that has been used in the Navy onboard naval surface vessels and submarines for decades. There are several variants in existence today that are able to employ a 1000lbs High Explosive or Combined Effects warhead against targets up to 1,500nm away (U.S. Navy 2014). The latest generation TLAM has a significant amount of UAS-type network capabilities that allow the missile to communicate with and use targeting data from other platforms (Naval Air Systems Command 2014). Additional capabilities include in flight re-targeting, ability to loiter for emerging targets, and onboard cameras that can provide battle damage assessments (Naval Air Systems Command 2014). While current versions do not have a moving target capability, improvements are currently being developed to allow for land and sea moving targets (Raytheon 2014). Advanced Anti-Radiation capability is also being considered for future blocks (U.S. Navy 2012). Overall, the team assessed that TLAM, due to its significant capabilities, small size, and operational maturity, would make an exceptional Strike platform to integrate into the Sea Scout concept.

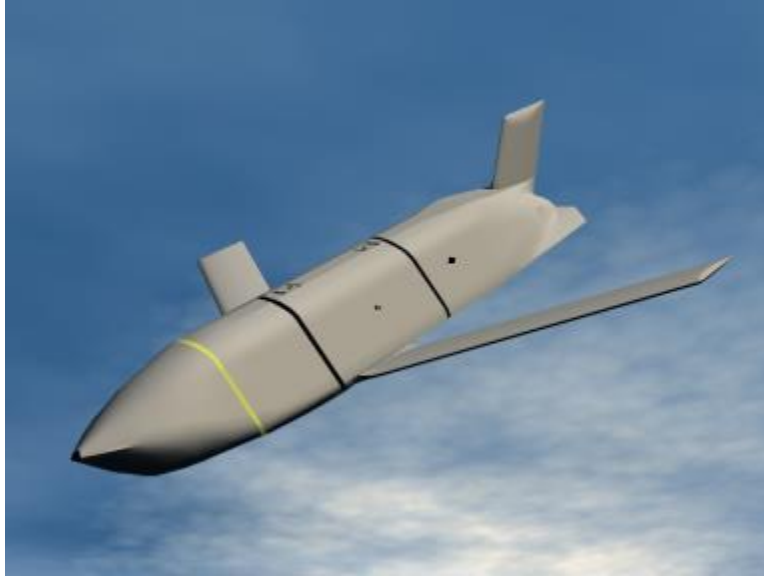


Figure 65. Long Range Anti-Ship Missile (from Defense Industry Daily 2014).

LRASM is a missile system that is currently being developed by DARPA for the U.S. Navy as a stop-gap measure to replace the insufficiently ranged Harpoon missile (Majumdar 2014). It leverages the design of the currently operational Joint Air-to-Surface Standoff Missile (JASSM) employed by U.S. fighter aircraft since 2009 (Mabbett 2013). LRASM will build on JASSM's 230+nm range and low observability by adding capabilities specifically tailored to the Surface Strike mission. These capabilities include data-link updates, a sea skimming terminal profile, and the ability to autonomously acquire and identify moving surface targets through onboard target recognition algorithms (Mabbett 2013). The system is designed to be compatible with the Mk-41 Vertical Launching System (VLS) and successfully demonstrated the ability to launch from a VLS in January 2014 (Lockheed Martin 2014). To date, the system has demonstrated that it can successfully detect, engage and hit a moving surface target (Defense Advanced Research Projects Agency 2013). LRASM is transitioning from concept demonstration to the developmental phase in FY14 and aims to be operational by 2018 (Osborn 2014). This timeline allows sufficient time for LRASM to be successfully integrated into the initial installment of the Sea Scout system.

All things considered, the team concluded that the implementation of both missiles, LRASM for Surface Strike, and TLAM for Land Strike, presented the most

logical options to provide a capable, cost-effective and expedient airborne Strike capability to the Sea Scout system. The VLS proved to be the integrating factor that allows for both platforms to easily fold into the Sea Scout concept.

A spatial analysis was again conducted on the CVE layout to determine where VLS systems could be placed, how many would fit, and whether the reconfiguration could be done without affecting Hummingbird operations.

Due to the catamaran hull utilized in the CVE design, it was determined that VLS systems would have to be positioned towards the outboard of the vessel to accommodate their height of 26 feet. Since fuel cells are located in the aft catamarans, the only location they could fit would be in the forward catamarans. In regard to vertical placement, the top of the VLS would lie flush with the Main Deck with the remainder of the structure extending below through the Hangar Deck and into the Second Deck. Due to the overhanging superstructure, the VLS canisters would only be able to run forward to aft for a length of ~100 feet. This would limit the amount of VLSs onboard the CVE to seven; four cell canisters on each side for a total missile capacity of 56 missiles. While the addition of VLS canisters would take up some additional space, the team assessed that they would not significantly affect the embarkation or operations of the A130 Hummingbird platform onboard the CVE. Figure 66. depicts the redesigned layout of the CVE Main Deck and Hangar Deck.

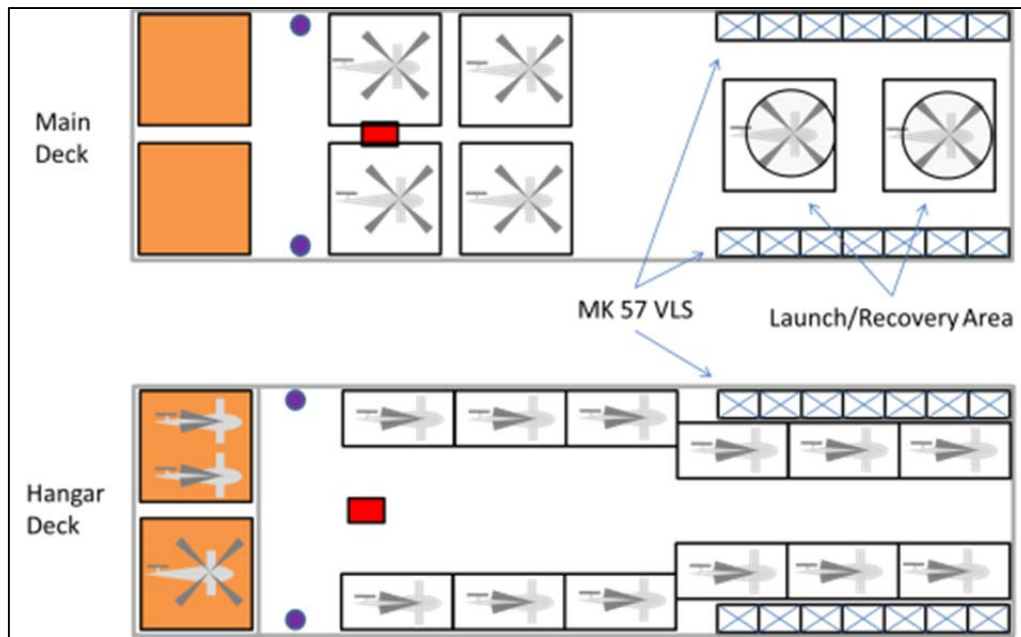


Figure 66. CVE deck layout with VLS canisters.

2. Surface Strike and Decoy Analysis

With the selection of the LRASM as the Surface Strike platform for the system, an analysis was conducted to determine what effect the additional assets would have in a surface exchange when employed within a Surface Action Group or Flotilla concept. The analysis also explored the use of mixing BQM decoys into the salvo to determine if their employment was a viable low-cost way to saturate enemy defensive systems and increase the expected number of mission-kills.

a. Model Scenario Vignette

The model was constructed within the context of the South China Sea scenario. The vignette begins when a Hummingbird detects, identifies, and relays that it has discovered a group of Red enemy surface combatants approaching the Blue SAG from a bearing of 030 degrees at 194nm. Among the information sent is also the number and classes of warships identified, area images, and coordinates for the current center-point of the formation as well as its last speed and heading. The Tactical Action Officer (TAO) utilizes the imagery to confirm the hostile assessment of the system's onboard target identification algorithms. The targets are then correlated and declared hostile via the

Aegis fire control system and the Hummingbird is directed to establish an orbit 50nm South-southwest of the enemy group.

Next, targeting information is uploaded into LRASMs aboard the various vessels within the SAG including the Sea Scout CVE. A coordinated salvo of missiles and decoys is volleyed toward the enemy combatants to achieve a precise time on top.

The enemy detects the inbound salvo and applies both area and point defense systems to the incoming bogeys. Unable to sort actual missiles from decoys, the area defense systems attempt to target as many inbounds as possible. While some of the bogeys are successfully targeted, the sheer number is beyond the capacity of the system and several make it through.

The LRASMs that get through the area defense open their seekers and begin to identify and lock onto targets. BQMs that survive continue on. Without precise final guidance measures, they do not get close enough to the combatants to be engaged by point defense systems.

The enemy's Close in Weapons Systems (CIWSs) attempt to engage the inbound LRASMs, but they are overwhelmed by the numbers that have gotten through. At the designated time on top, the LRASMs' high explosive warheads wreak havoc on the enemy SAG.

After the predicted time of impact, the Hummingbird asset is directed to investigate and provide a battle damage assessment. The UAS moves to the target area and relays the information back to the TAO, who confers with the Commander on the next move.

b. Modeling Method

SIMIO was utilized to model the weapons exchange scenario outlined above. The SIMIO program is a discrete event simulation tool that allows modeling of stochastic networks, where agents move along arcs and "queue-up" for service at nodes. Transit times and service times can be drawn from specified probability distributions.

The model consists of four basic elements; entities, sources, servers and sinks. The entities (anti-ship missiles and decoys in this case) are created by the sources. The

servers (enemy surface-to-air missiles and CIWS in this case) process the entities; and the sinks destroy them. Probabilistic paths and nodes link all of the basic elements together and direct the flow of entities through the model.

Explanation for how the model works is to best conveyed via the flow of the entities through the model as depicted in Figure 67. Starting from the left and working right, ships firing anti-surface missiles and decoys are represented by a source. When the modeling run begins, the source generates entities, which represent a single anti-ship missile or decoy. Missiles are fired according to an exponential distribution with a mean of 7 seconds until the designated number of missiles and decoys for the salvo has been released. Once released, the missiles and decoys travel to the first node where they are essentially shuffled like a deck of cards.

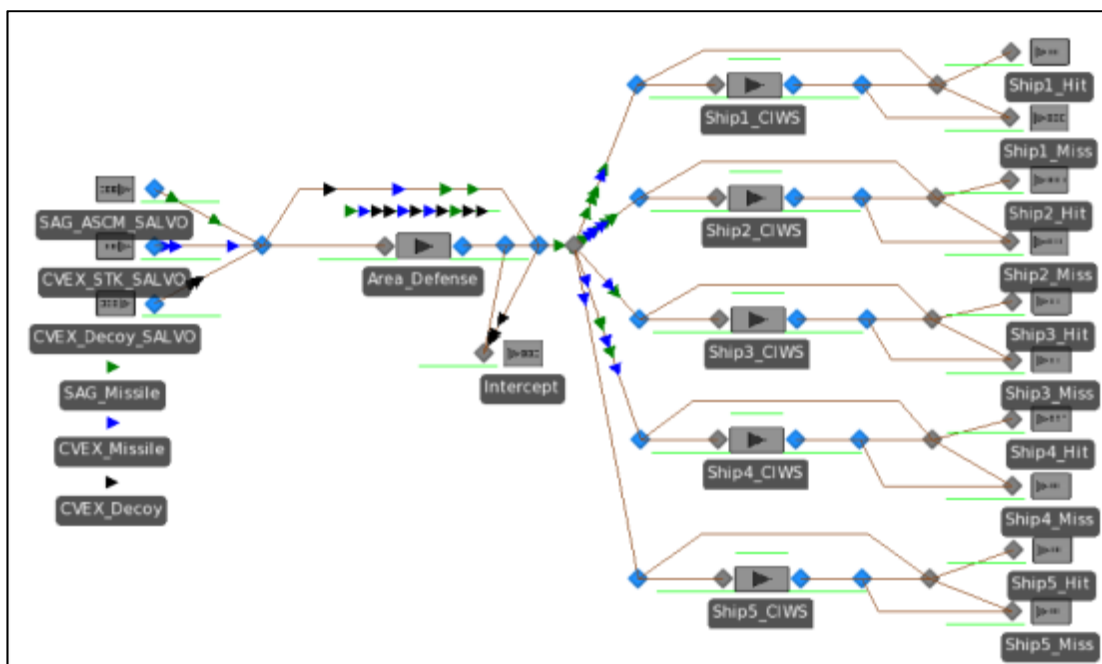


Figure 67. SIMIO model example.

Next, the missiles flow to the area defense server which represents the defending SAG's surface-to-air missile targeting capacity. The server becomes full when the number of missiles that has entered equals the defending SAG's assumed maximum targeting capacity as shown in Table 16. At this point, missiles that have not entered the server bypass and move on to the point defense section of the model. Those entities that

have entered the area defense server are sorted probabilistically based on the surface-to-air missile probability of kill. Surviving anti-ship missiles and decoys are sent to the point defense section while destroyed entities are discarded.

Once making it successfully past the area defense server, decoys are removed from the model (since it is assumed that they will not get close enough to the point defense systems to be engaged). Surviving anti-ship missiles are evenly distributed among the defending SAG's vessels where they are processed by the point defense servers.

Point defense servers work in the same manner as the area defense server and are bypassed when the assumed capacity has been reached, see Table 16. Anti-ship missiles that either bypass or survive the point defense server go on to a hit/miss node where they are probabilistically sorted into the hit or miss sink based on probability of kill. Enemy casualties that reduce defensive capabilities are accounted for through programming logic that removes a ship's defense measures when it is destroyed.

The program tallies the number of hits on defending ships by counting the number of anti-ship missiles that enter the sinks. The single-hit mission-kill criterion is then applied resulting in the number of kills the anti-ship missile salvo achieved. This process is then simulated multiple times to tabulate the mean value of ships destroyed given a SAG configuration.

c. Model Assumptions

The table below lists the ship classes and their assumed capability parameters utilized within the SIMIO model. The number and types of missiles that a certain class could hold was based on open source information. In cases where a ship's mixture of missiles could vary given VLS launcher capability, plausible load-outs were assumed. Also, the individual Probability of Kill (P_k) of missiles, CIWS systems, and system targeting capacities are notional.

Combat Vessel	Surface-to-Air Missile	Surface-to-Surface Missile	Point Defense Capability	Source(s)
Blue Forces				
Arleigh Burke Class DDG	64 x SM-2 -Pk: .90 -Target Capacity: 12 per salvo	16 x LRASM -Pk: .90 -Fired per Salvo: 8	2 x CIWS -Pk: .30	(IHS Jane's 2014)
CVE	None	56 x LRASM Pk: .90 Fired per Salvo: 20	2 x CIWS Pk: .30 42 x RAM Pk: .96	(Levine et al. 2013)
Red Forces				
Type 52D DDG	64 x HHQ-9B -Pk: .70 -Target Capacity: 16 per salvo	16 x C-805 Pk: .90 -Fired per Salvo: 8	2 x Type 730 CIWS Pk: .30 - Ammo Capacity: 2 x 4 sec. burst each	(IHS Jane's 2014)
Type 52C DDG	64 x HHQ-9B -Pk: .70 -Target Capacity: 16 per salvo	16 x C-805 Pk: .90 -Fired per Salvo: 8	2 x Type 730 CIWS Pk: .30 - Ammo Capacity: 2 x 4 sec. burst each	(IHS Jane's 2014)
Sovremenny DDG	44 x SA-N-7 -Pk: .70 -Target Capacity: 12 per salvo	8 x SS-N-22 Pk: .90 -Fired per salvo: 8	4 x AK630 CIWS Pk: .30 -Ammo Capacity: 2 x 4 sec. burst each	(IHS Jane's 2013)
Type 22 Missile Boat	None	8 x C-802 Pk: .90 -Fired per salvo: 4	1 x AK630 Pk: .30 -Ammo Capacity: 2 x 4 sec. burst each	(IHS Jane's 2013)

Table 16. Blue and Red force modeling parameters.

Additional assumptions:

- Red forces were alert and able to provide 100% of their defense capabilities against the entire inbound salvo until destroyed
- Red targeting capacity was not randomized
- Red forces were targeted outside of their anti-ship missile range. They did not fire any anti-ship missile salvos in return
- Red shoots only one surface-to-air missile per targeted LRASM.
- Soft-kill missile defenses such as chaff were not modeled
- BQM target-drones were applied to area defenses only, and were not targeted by point defenses
- CVE could fire a maximum of 20 missiles at a rate of two missiles every seven seconds

d. Modeling Cases

Given the different enemy SAG compositions plausible within the scenario, several cases were utilized to explore the offensive surface missile and decoy combination's potential in various Red vs. Blue exchanges. The goal of the different Red force structures was to provide a wide range of defensive capability to determine what cases, if any, might benefit from the use of decoys. Table 17. lists the Blue force vs. Red force combinations tested.

Blue Force Composition	Case	Red Force Composition
3 x DDG 1 x Sea Scout	1	1 x Sovremenny 2 x Type 52D 2 x Type 52C
	2	15 x Type 22
	3	15 x Type 22 2 x Type 52 C

Table 17. Cases modeled.

e. *Results and Analysis*

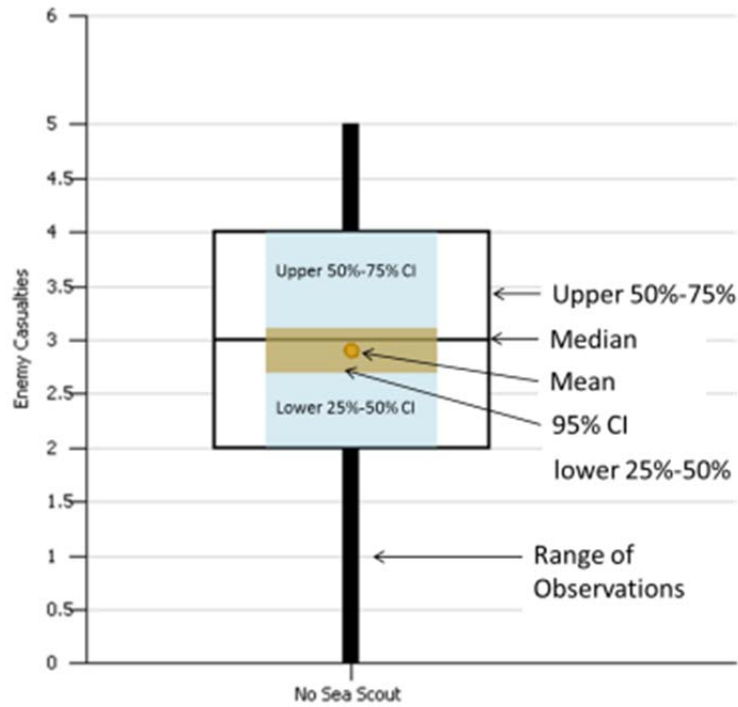


Figure 68. SIMIO Figure Legend.

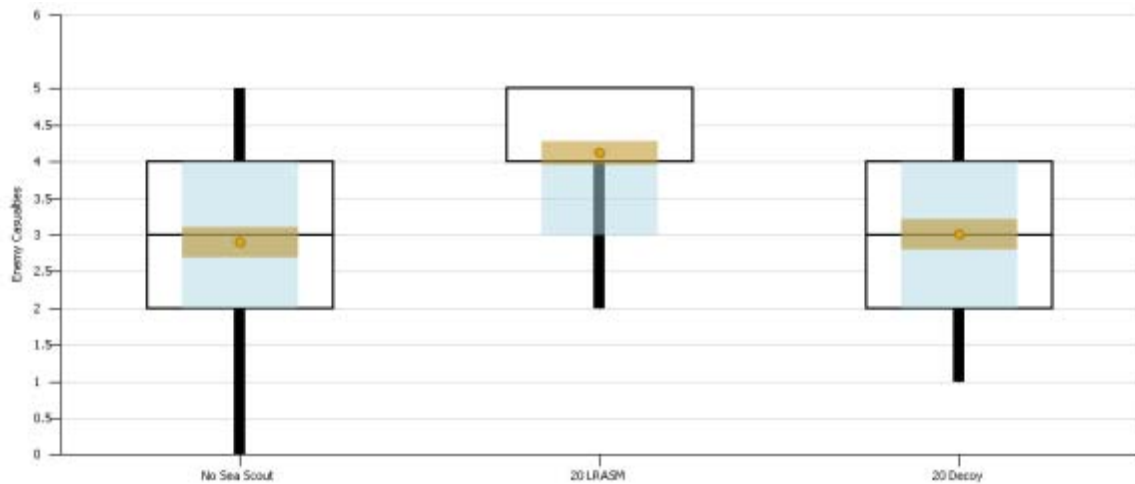


Figure 69. Case 1, LRASM vs Decoy results.

Figure 69 shows the results from the Case 1 which pits three DDGs and a single Sea Scout CVE against five robust Chinese DDGs. In the “No Sea Scout” run, 24 LRASM from the three DDGs resulted in a mean number of casualties of about three.

With the additional 20 LRASM provided by the Sea Scout CVE in the next run, the mean number of enemy casualties increased from three to four. The additional LRASMs also had the effect of ensuring that the enemy SAG experienced at least two casualties in a single salvo.

The employment of decoys had no effect on the mean number of casualties, but they did increase the minimum number of casualties observed from zero to one. There is likely no significant decoy effect due to the fact that the area defense has enough capacity (the DDGs can target up to 72 inbound missiles in this case) to target all inbound missiles and decoys with surface-to-air missiles.

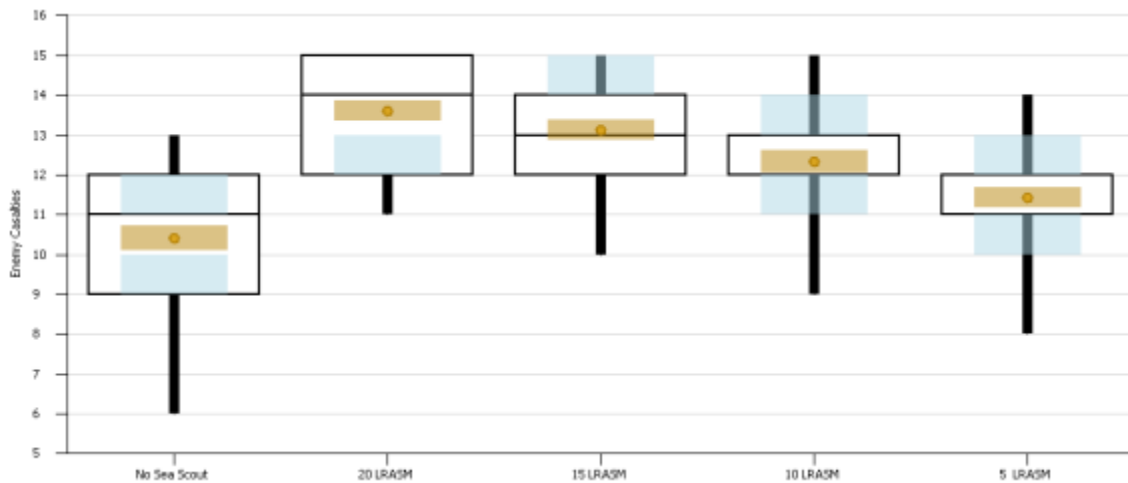


Figure 70. Case 2, LRASM only results.

In Case 2, which pits the Blue SAG against 15 Type 22 missile boats, the addition of the Sea Scout CVE significantly affects the range of enemy casualties by increasing the minimum from six (in the No Sea Scout run) to 11 when a maximum salvo of 20 LRASM are fired by the Sea Scout CVE in the next run. The mean number of Red Type 22 missile boat casualties also increases from 10.41 to 13.62.

There were no decoy effects in Case 2 because the Type 22 missile boats do not have an area defense capability.

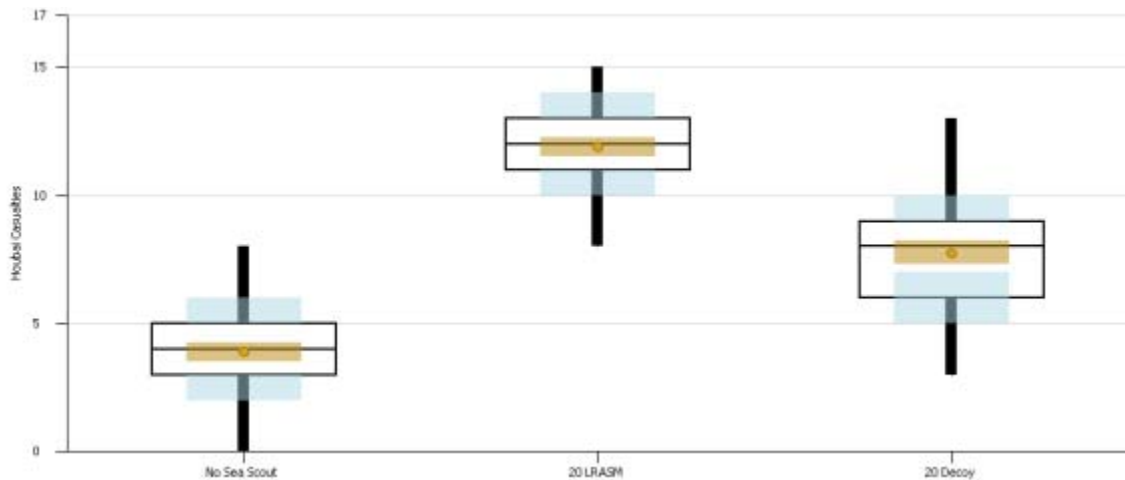


Figure 71. Case 3 LRASM vs Decoy results.

Case 3 adds two Type 52C DDGs to the enemy SAG which provides an area defense capability to target up to 28 missiles. In the “No Sea Scout” run, this resulted in an appreciable decrease in the mean number of Red Type 22 missile boat casualties, down from 10.41 in Case 2 to 3.91. However, the additional 20 LRASM delivered by the Sea Scout CVE in the next run resulted in a mean of 11.89 Type 22 missile boat casualties.

In this case, there was also a significant effect in the 20 Decoy run. The addition of decoys provided by the Sea Scout CVE to the DDG salvo resulted in a mean of 8.43 enemy kills compared to the “No Sea Scout” run mean of 3.91 kills.

The effect of using decoys in Case 3 was explored further by doing a cost comparison of the dollar value to obtain a kill with various numbers of LRASM and BQM decoy assets. The Sea Scout CVE salvos were tested incrementally with up to 40 additional missiles or decoys added to the DDGs’ salvo (an additional Sea Scout CVE platform was assumed into the SAG for a total of two).

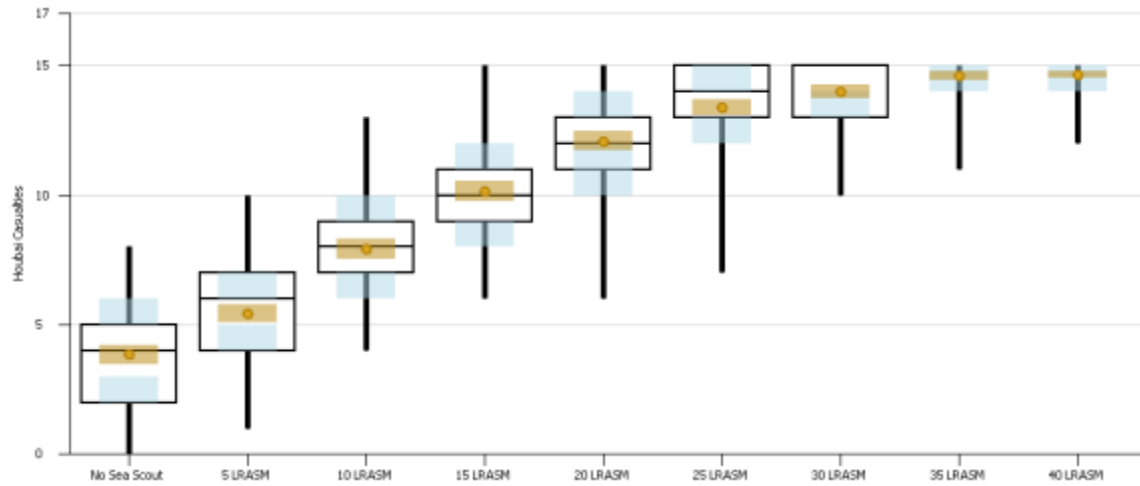


Figure 72. Incremental effects of adding LRASM to the Sea Scout CVE salvo with up to two Sea Scout CVE platforms.

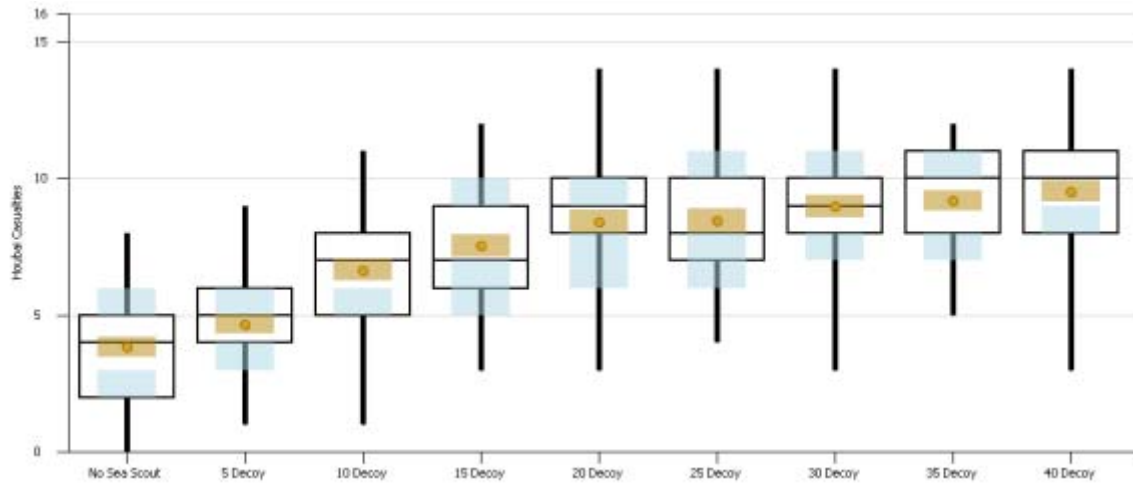


Figure 73. Incremental effects of adding BQM decoys to the Sea Scout CVE salvo with up to two Sea Scout CVE platforms.

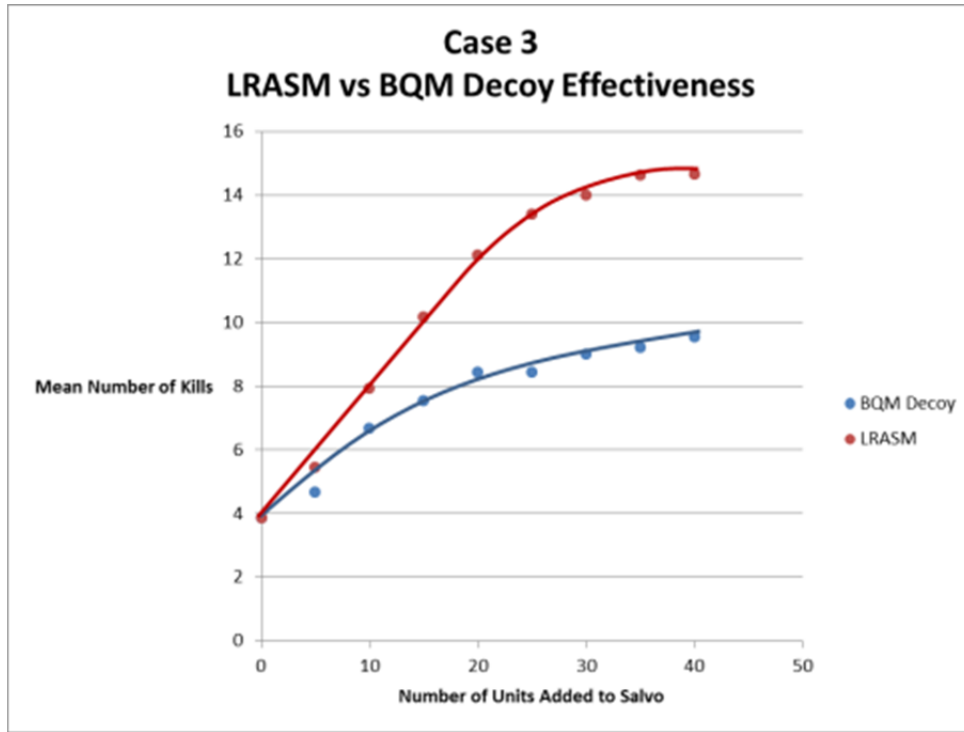


Figure 74. LRASM vs. Decoy Effectiveness.

As indicated by Figure 74, the effectiveness of providing extra LRASMs to the salvo is significantly higher than adding decoys. In this case, LRASM is clearly the better choice. However, the cost of achieving this effectiveness tells a different story.

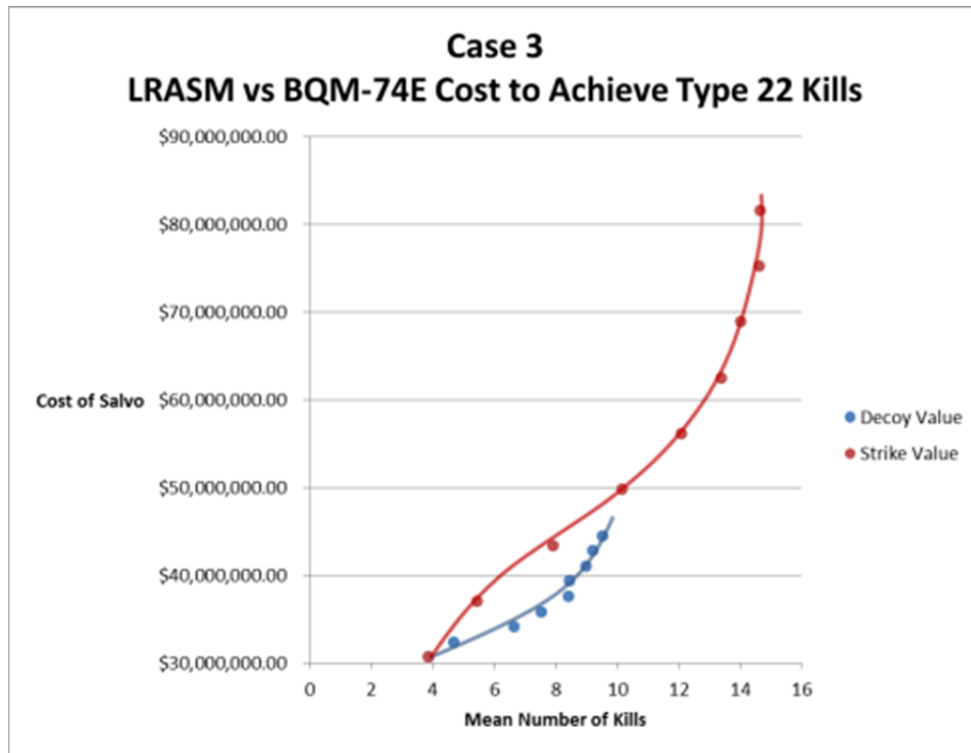


Figure 75. LRASM vs. BQM-74E Cost to achieve Type 22 missile boat kills.

The graph in Figure 75 shows the relationship between total salvo cost and mean number of Type 22 missile boat kills achieved. In regard to the BQM-74E decoy, its cost is low enough compared to LRASM to provide increased savings over LRASM up to about eight kills. After eight kills the savings area decreases. The BQM-74E decoy is the better cost option up to about 10 kills; however, in order to achieve this effectiveness, 40 BQM decoys would need to be launched in a salvo. By interpolation, the maximum savings of \$35M-\$37M around the eight-kill point is achieved when a salvo of 20 BQM decoy drones are launched from the Sea Scout CVE.

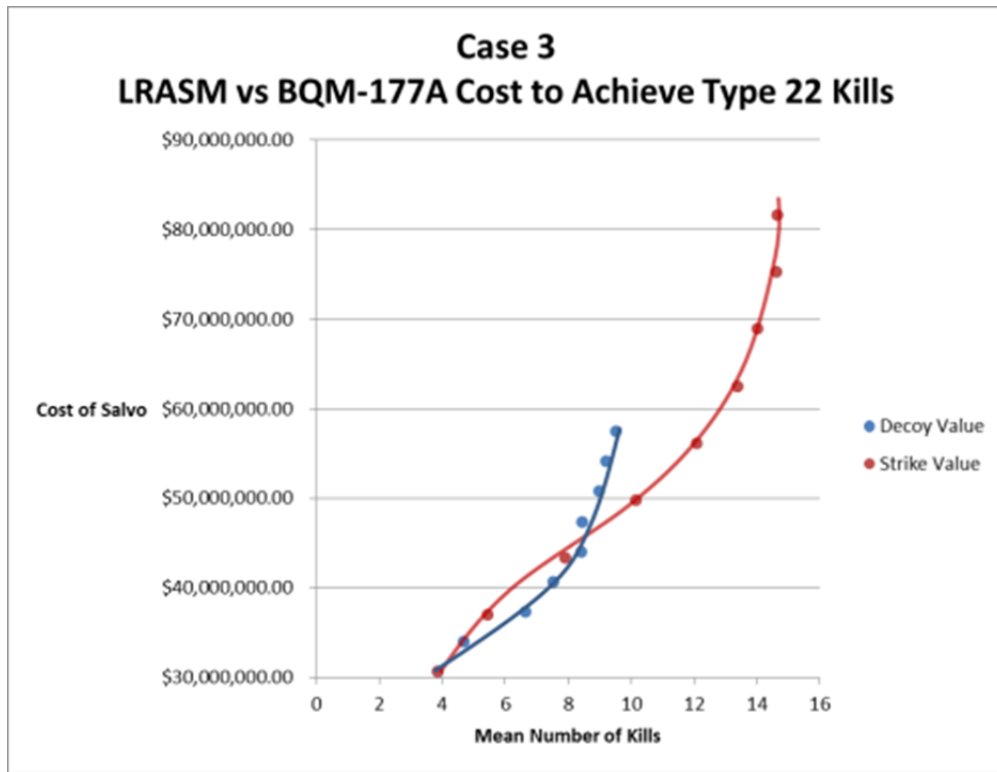


Figure 76. LRASM vs. BQM-177A Cost to achieve Type 22 missile boat kills.

In regard to the cost of BQM-177A, there is still a savings. In this case, the cost effectiveness is negated at around eight kills where LRASM's effectiveness becomes the more cost-effective option.

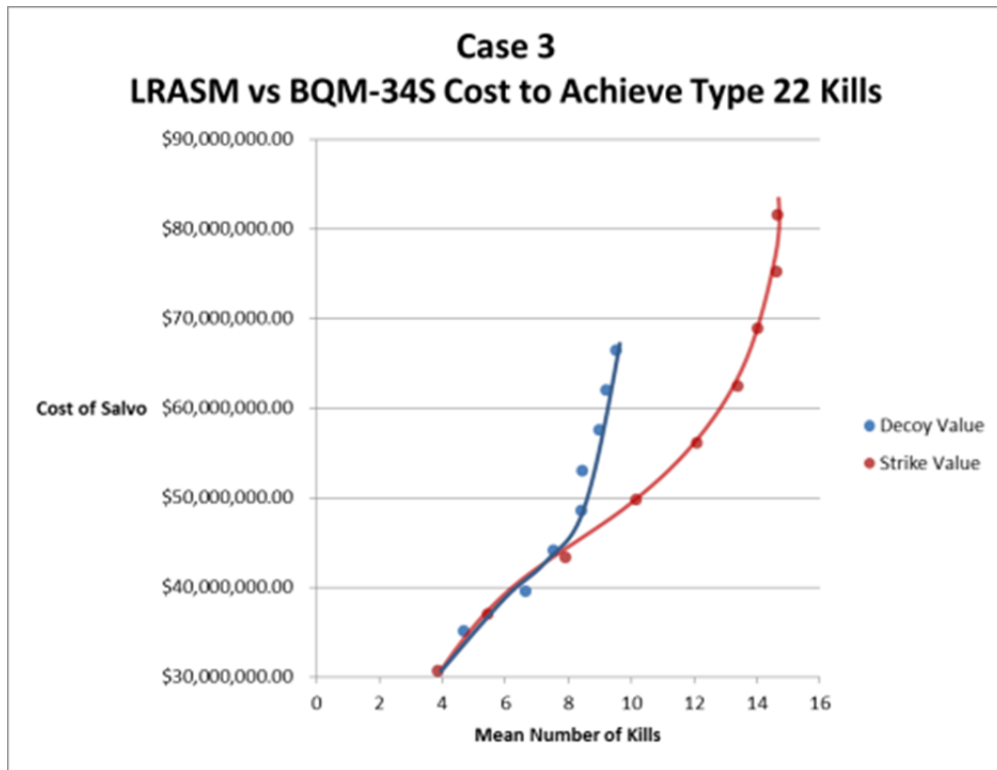


Figure 77. LRASM vs. BQM-34S Cost to achieve Type 22 missile boat kills.

In Figure 77 the cost curve of the BQM-34S aligns with LRASM up until about eight kills, and then departs significantly in favor of LRASM showing no potential savings.

f. Implications

The analysis shows that the additional fire power added when Sea Scout employs LRASM has significant effects in regard to the attrition of enemy forces in all cases. Therefore, the addition of LRASM into the magazine of Sea Scout is recommended, especially when surface engagements are likely.

In regard to the use of decoys to overwhelm area defenses, it was found that this tactic was only effective when area defensive capacities could be overrun, allowing assets to go through untargeted. In cases where area defenses had the capacity to target all inbound assets, decoy use had little to no effect.

On the matter of cost effectiveness, when decoys combined with anti-ship missiles could over capacitate area defenses, the cost difference between the Strike asset

and the decoy asset determines whether decoys are worth employing. In the case of the BQM-74E, its unit cost was low enough to achieve substantial savings given a desired effect.

Considering the case-dependent effectiveness of BQM employment as a decoy within a strike salvo, the team decided that mixed LRASM/BQM decoy salvos were not especially advantageous over the use of LRASM-only salvos. Therefore, the overall design of Sea Scout should not be prioritized to the use of BQMs. Considering this finding, the team recommends that the Electromagnetic Aircraft Launch System (EMALS) catapults be removed from the CVE design and VLS canisters be installed instead. If utilization of BQMs is required or desired in the future for other possible Sea Scout missions, removal of the catapult will not preclude their use, as Jet-Assisted Take-Off (JATO) methods will allow their employment from the CVE flight deck.

3. Sea Scout Concept Conclusion

The Sea Scout concept capitalizes on all of the advantages that the baseline Sea Vex concept sought to enable, and utilizes a cheaper smaller vessel to distribute airborne capability throughout the fleet at a superior value. While the capabilities designed into Sea Scout are not as broad as those imagined in Sea Vex, the focused design of three critical capabilities allows for the system to provide a decisive amount of ISR, Surface Strike, and Land Strike capability in the absence of manned CVW assets.

a. Sea Scout Final System Design Concept

The Sea Scout system comprises three major warfighting systems; a small fast CVE ship, 21 A160 Hummingbird UASs, and a configurable mixture of 56 VLS launched TLAM or LRASM missiles.

The A160 Hummingbird is an autonomous VTOL UAS that provides the eyes and ears for the fleet. It's far reaching range, tremendous endurance and sophisticated sensors enable the platform to serve as a fleet scout that can detect the enemy well before they get close enough to pose a threat. The Hummingbird's sensors and data-links enable TLAM and LRASM to achieve their full potential against dynamic land and surface targets. Over land or over sea, the system can be utilized to collect the full spectrum of information

across a vast range of ISR mission sets. With its 2,500lbs payload capacity and integration of the Hellfire air-to-surface strike missiles, it has capacity for growth and taking on additional mission sets in future increments.

The combination of LRASM and TLAM enable Sea Scout to provide critical Strike capabilities on both land and water from ranges that far exceed today's strike fighter aircraft at significantly lower risk. Both platforms are network-ready and have the ability to integrate with manned and unmanned fleet assets as wells as provide flexible targeting options to the Commander.

A squadron of Sea Scout CVEs dispersed throughout the fleet would provide distributed Strike and ISR capabilities to areas that pose too high of a risk for the CVN/CVW system. Combined with CVW assets, the Sea Scout system would allow manned and unmanned platforms from the carrier to shed much of the ISR and Strike responsibilities in order to focus on other critical mission areas such as DCA and OCA. Alternatively, in situations that require excessive capability, the Sea Scout system-of-systems would become a force multiplier coordinating with manned platforms to deliver devastating fire-power. Whether aggregated in a SAG or CSG, Sea Scout brings distributed capability to the fight.

It is important to note that Sea Scout is not a lone wolf platform. While the CVE does have point defense systems onboard, its lack of dedicated air defense capability requires it to be protected under the umbrella of air defense systems such as Aegis or manned and unmanned fighter aircraft. Although, when small scale autonomous airborne UAS swarm technologies mature, a future increment of the Sea Scout systems could step into the air-to-air arena.

The Sea Scout system-of-systems has capacity for growth. The CVE itself has the space for more platforms, and the Hummingbird has room to integrate more sensors and weapons as well. As UAS technologies improve, more critical capabilities such as Electronic Warfare, Mine Warfare and Anti-Submarine Warfare could be added in later increments. While the first increment of Sea Scout may not be able to completely replicate CVW capabilities, with potential for growth and the rapid advancement of UAS technology, it is plausible the later third or fourth increment will fit the bill.

IX. DAW SOLUTION PART 3: THE MTX CONCEPT

A. CLOSING THE CAPABILITY GAP

The concept of the unmanned “missile-truck” (MTX) was developed by the team to address the possible need for increased Offensive Counter-Air (OCA), Defensive Counter-Air (DCA), and Early Warning capability that may arise when the manned assets on the CVN (or EABs) are limited by range and threatened within the A2AD environment.

Closing this capability gap reduces risk to human life while increasing range, payload, and deception which are imperative to increase the probability to overcome the A2AD threats and win a conflict in the South China Sea.

B. MTX CONCEPT DESCRIPTION

The Missile-Truck Concept (MTX) leverages unmanned technology in order to gain a decisive advantage in the battle for air superiority outside of traditional carrier air wing range. The key to the MTX concept rests with two key sub-concepts. First is the ability to slave an unmanned air vehicle (“missile-truck” UAV) to a manned fighter platform (F/A-18 Hornet, F-16 Falcon, etc.) while conducting OCA missions. Second is the ability to control a separate type of “missile-truck” UAV from a land- or sea-based static control station to conduct DCA missions.

For OCA missions, the firepower available to the manned aircraft would be significantly increased with the addition of a slaved missile-truck. The Weapons System Officer (WSO) would have control over a higher payload with an extended flight profile range, reducing risk by conducting the tactical mission with an unmanned system from an extended distance.

For DCA operations, the ability to deploy missile-truck UAVs controlled from land- or sea-based control stations, provides the U.S. forces with the defense capabilities and air superiority it currently owns when using a Carrier Strike Group (CSG) (Goure 2011) without putting the high value unit at risk. Maintaining the capability to conduct DCA is imperative to protect the nation’s air bases, sea bases, surface action groups, and

Carrier Strike Group. Providing a dedicated Early Warning missile-truck UAV with increased endurance and payload capability, would increase the ability to disrupt or deter adversary air strikes before they pose a threat while simultaneously providing the capability to defend U.S. forces long enough to launch manned aircraft to engage incoming threats.

C. MTX HIGH-LEVEL REQUIREMENTS

The following high-level requirements would allow the achievement of the envisaged capability of the Missile-Truck Concept.

(1) Unmanned Control. The missile-truck UAV should have the ability to be slaved to and remotely controlled by a Weapon Systems Officer onboard a manned air asset. It should also have the ability to be controlled from designated land- or sea-based control station. If technology and budget allow, it would be desirable for the Missile-truck UAV to be capable of autonomous operation.

(2) Missile Payload. The missile-truck UAV shall have the ability to carry a mix of eight-to-ten Advanced Medium-Range Air to Air Missiles (AMRAAM) and Air to Ground Missiles (AGM) such as the AGM-65 Maverick to perform its mission. The quantity listed is based on the maximum payload of the legacy F/A-18s (Raytheon 2014). Having this requirement would increase the air-to-air firepower of the air asset that the missile-truck UAV is being slaved to.

(3) Endurance. The missile-truck UAV shall have the ability to operate longer than the air asset that it is slaved to as to enable it to be projected deeper into adversaries' territory to conduct OCA missions and be able to sustain flight back to base. At the moment, the master platform has yet to be designated; however, when reference to F/A-18 as the master platform, the missile-truck UAV should minimally endure approximately 1.5 times longer than the F/A-18. This is to be accomplished through modifications made to the aircraft by removing the modules used by the pilot that are no longer needed making the craft lighter and allowing room for additional fuel cells.

(4) **Stealth.** It is desirable for a future missile-truck UAV variant to have a reasonable amount of stealth capability to improve its survivability and chances of mission success. The reduced Radar Cross Section of the missile-truck UAV variant lowers the possibility of being detected by adversaries' radars. However, the level of stealth would have to be balanced against cost. Later in the report a platform recommendation for a stealthier UAV variant (other than the QF-18) is discussed.

(5) **Air Refuel Capable.** The missile-truck should be air refuel capable. This capability allows the Missile-truck UAV to remain airborne for extended periods of time, which would provide the U.S. Navy with a persistent DCA capability. The ability to refuel an unmanned aircraft while in flight is a capability that requires further research and development; however, the capability for midair air refueling should exist until technology catches up MTX CONOPS

(6) **Offensive Counter-Air Mission.** OCA seeks to suppress and disrupt the enemy's military air power by destroying its air assets (i.e., aircraft and missiles) and their supporting infrastructures before and after launch, as close to the source as possible. The MTX concept can be integrated into the Distributed Air Wing (DAW) concept or the traditional CSG concept to provide the increase in strike power required in an A2AD environment, with a lower cost while reducing the risk to personnel and military assets (Defense Systems Staff 2013).

b. Platform for OCA role: Modified F/A-18 hornet (QF-18)

Utilizing the legacy Hornet design has significant inherent benefits. It is a proven airframe with radar and weapon systems already integrated. It can carry up to 10 AIM-120 AMRAAM missiles when utilizing both under-wing and fuselage pylons (Jenkins 2000). Furthermore, it is effectively a sunk cost; the systems have already been bought and paid for, and will eventually be phased out and replaced by either Super Hornets or F-35C Joint Strike Fighters over the next few decades (Gertler 2009).

Utilization of an unmanned asset in the OCA role would require significant modification, but would yield additional benefit. While installation of the required data link capability and flight control systems would likely be both complex and expensive, it is unlikely this equipment would weigh more than the now-extraneous equipment that

could be removed. Items such as the M61 cannon, ejection seat, cockpit displays and other avionics, as well as all life-support equipment could be removed, yielding weight savings and increasing performance or payload.

In the OCA role, each QF-18 will be fully loaded with ten AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM), slaved to a master manned dual-cockpit F/A-18F (or F-35C when available). The master aircraft will be armed with four AMRAAM and two GBU-31 precision guided bombs. Four pair of F/A-18F + QF-18, a total of four manned and four unmanned aircraft will form a “UAS-enhanced Self Escort Strike” with a total weapons payload of 56 AIM-120 and eight GBU-31s. It should be noted that this is a typical configuration of a strike package for OCA role and can be varied depending on mission needs and threat complexity.

c. Control Concepts and Operation

When activated for OCA missions, the strike package of eight aircraft will be launched from the designated Hub/TSB/CVN. The four manned F/A-18F will take off ahead of the four unmanned QF-18 upon activation and fly to the rendezvous waypoint. Subsequently, the four QF-18s will be launched from the Hub/TSB/CVN, with the launching conducted by controllers located on the Dispersed Bases or CVN. After take-off, the QF-18 will fly to the rendezvous waypoint where the control of the aircraft will be handed over to the Weapons System Officer (WSO) in the back cockpit of the F/A-18F. Thereafter the QF-18 will be controlled by WSOs via line-of-sight communication onboard the aircraft. Once all four QF-18 are paired up with their master aircraft, the strike package will carry out the various UAS enhanced Self Escort Strike missions such as air-to-air, air-to-ground, fighter sweeps, or escort assignments.

The WSOs will have the capability of directing the paired QF-18s and also have full access to its fire control system. When the strike package formation is within the radar targeting range, the WSO will appropriately target the QF-18s into hostile enemy aircraft factor groups. If the strike package manages to destroy all enemy aircraft in the engagement and penetrate deep into enemy territory through in-flight refueling, the BRU-31 on the F/A-18F will be used to destroy key infrastructures, crippling and preventing

the enemy from further response. Even if the QF-18s expend all their weapons, they could potentially stay in theater to act as targeting decoys to further confuse the enemy.

Upon completion of its mission, the strike package will return to home base with the F/A-18F passing control of its assigned QF-18 to the ground controllers or AWACS before landing.

In an A2AD environment, conducting Early Warning missions entails a broad spectrum of mission sets that are critical to ensure the success of DCA and OCA missions. Air platforms chosen to perform Early Warning missions must have range and endurance to penetrate deep into the region of conflict. DCA missions attempt to secure an area where friendly forces can operate effectively by denying the enemy the freedom to carry out offensive air operations. Effective execution of DCA requires early warning of enemy air attack from Early Warning so that early engagement and defense in depth are achieved. Incorporating MTX with DAW or traditional CVN concepts will enhance mission effectiveness with a reduced risk to personnel in an A2AD environment.

d. Platform for DCA / Early Warning role: MQF-X

One proposed system (hereafter referred to as the MQF-X) would be capable of fully autonomous operation either from an aircraft carrier or from forward dispersed airfields. It would carry eight to twelve AIM-120C/D AMRAAM missiles, for a total combat payload of approximately 2,760 to 4,140lbs. This payload is comparable to the General Atomics MQ-9 Reaper combat drone, which has an approximate payload capacity of 3,750lbs (U.S. Air Force 2010). The weapons could either be carried externally, or alternatively, in an internal bay to reduce radar cross section as well as aerodynamic drag.

The airframe could incorporate some aspects of stealth technology to minimize the radar cross section, balanced against cost. Extensive use of composite materiel would reduce both weight and RCS. Thrust and power would be provided by one or two highly efficient turbofan or turboprop engines. With no aircrew, weight is greatly reduced as there is no requirement for life support, avionics, or survivability measures. To take full advantage of this mass reduction, the data-link equipment,

including transceivers and processors, should be designed to incorporate weight-saving features. As it would be entirely dependent on cueing from external platforms, there would be no requirement for onboard sensors, further reducing weight and power requirements. With no emitters, the signature of the platform is reduced further, allowing it to operate undetected at standoff ranges. Inclusion of certain types of sensors could be considered on a case-by-case basis. For instance, the inclusion of long-range electro-optical or infrared sensors could be considered to allow the platform the capability to assist in the detection and identification of potential threats. A passive electronic warfare capability could also be considered.

e. Control Concepts and Operation

The MQF-X can be controlled from a ground station, an AEGIS ship or an airborne platform such as the E-2D Hawkeye or the E-3 Sentry (Navy Recognition 2012). For missions requiring deep penetration, it is even conceivable that a radio buoy, deployed by a submarine, could link the unmanned aircraft via satellite data link to a remote ground control station. For the DCA/ Early Warning mission, a total of three MQF-X assets will constitute a DCA/ Early Warning package as shown in Figure 78. Each Hub/TSB/CVN will have at least two DCA/ Early Warning packages to ensure 24-hour coverage.

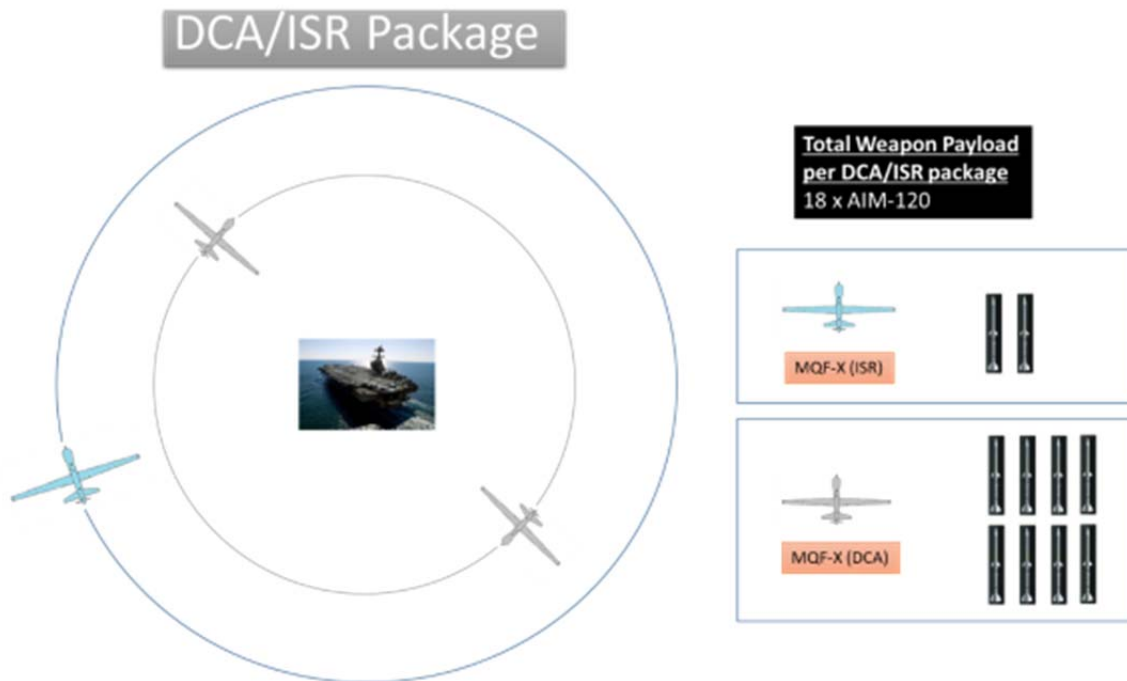


Figure 78. DCA/ Early Warning package comprising three MQF-X for 24 hours coverage.

During DCA/ Early Warning missions, when enemy aircraft is detected, the DCA package will intercept the incoming threat before more fighters are scrambled from the Hub/TSB/CVN for reinforcement.

D. MTX CONCEPT ADVANTAGES

With the implementation of the MTX concept, the U.S. Navy will be better equipped to engage adversaries in a more efficient and cost-effective manner. As a force multiplier, the MTX concept leverages technology to provide more firepower capability with minimal increase in manpower.

Manpower management is a critical issue within the U.S. Navy and is not expected to go away anytime soon. Finding ways to reduce manpower while also reducing risk will always be beneficial regardless of the country's fiscal situation. With the MTX concept, this can be addressed, as it allows for two airborne assets in the sky to conduct air-to-air missions while essentially halving the required number of trained pilots to do so. Providing twice the amount of firepower, added range, and reducing risk translates to cost savings in today's budget-conscious environment. The foundation

technology that is required for the MTX is available, and when compared to the creation of an entirely new aircraft, the proposed alternative is cost effective. However, the existing technology for autonomous flight, slaved control, and engagement will need to be refined for the MTX concept to become a reality.

The MTX concept would be most effective if integrated into the Dispersed Air Wing solution than simply the traditional CSG force structure for the reasons outlined in the following sections.

1. Manpower and Logistics

If the MTX were to be integrated into the Dispersed Air Wing Operations concept solution, then instead of sending two CVWs for a campaign, only one CVW would be required. This is due to the force structure composition. Instead of having two manned aircraft, one manned aircraft would be launched along with an unmanned, both of which can launch from a Hub or Tactical Strategic Base. The firepower and operating assets brought about by one CVW can potentially be doubled. The logistic trail required to support a potential Dispersed Air Wing Hub or TSB would already be established and would not be as complex and expensive as maintaining and sustaining a Carrier-based air wing. The substantial daily operating costs necessary to operate a CVN at sea also make the Dispersed Air Wing solution a more fiscally responsible alternative. By adopting the MTX concept and employing it in conjunction with a DAW, the potential cost-saving and risk reducing effect will have a multiplier effect.

2. Increased Reach in the A2AD Environment

With the MTX concept, the drone that is slaved to the manned aircraft can be placed in front of the later to provide a longer range of operation. This will augment the already closer reach of the Hubs and TSBs that would exist, especially in a situation where the CSG may need to be stationed outside the A2AD threat umbrella.

E. MTX CONCEPT CHALLENGES

There are some aspects in regards to the development of the missile-truck concept that present an immediate challenge if it is to be pursued as a force structure addition.

Below is a list of obstacles the team determined when comparing the modified F/A-18, modified MQ-9, and the future autonomous unmanned platform the X-47B (which will be discussed below) as baseline aircraft that could be converted into missile-truck UAVs.

1. Current Platform Limitations

The platform for which the MTX capability is assigned will be a major factor in determining its exact range capabilities and Early Warning capabilities. If the current F/A-18 is used as the base structure of the OCA-mission missile-truck UAV (QF-18) it will be limited if launched from outside of the DF-21 range due to its 1,089 nautical mile range (U.S. Navy 2009). The same range limitation applies to the DCA-mission missile-truck UAV (MQ-X). The current MQ-9 Reaper has approximately the same range as the Hornet with a distance of 1,000 nautical miles (U.S. Air Force 2010). This range limitation is offset by its 14 hour loiter capability, making it more suited for a strictly DCA role. (U.S. Air Force 2010) If an F/A-18 or the MQ-9 frame is used, the asset will either need to “lily-pad” from multiple dispersed air bases, conduct aerial refueling, or be optimally stationed throughout the region. This limitation turned the team’s attention to the need for a future missile-truck platform, such as the X-47B.

The X-47B is an unmanned combat air vehicle (UCAV) that was designed to conduct operations from an aircraft carrier. Designed for semi-autonomous operation, as of this report the X-47B is still in its test phase. The subsonic aircraft has already conducted launches, touch-an-go landings, and recoveries onboard the *USS George H.W. Bush*. Compared to the F/A-18 and the MQ-9, the X-47B could be an ideal candidate to be operated within the MTX concept due to its autonomous design and much longer range of almost 2,100 nautical miles (Kazianas 2013). If the X-47B could be developed to increase its payload, maintain its range, and operate under similar control schemes, using it as the MTX frame would eliminate the need to use intermediate land bases to reach the frontlines.

2. UCLASS Program Development Costs

The cost for further development in safely operating and controlling unmanned aerial vehicles with new airframes and systems from a CVN is another challenge to the

MTX concept. The X-47B is a viable option for the MTX concept; however, it is still in the early stages of test and evaluation. In addition, integrating the desired control schemes as well as the ability to conduct OCA missions may not be feasible in terms of finding an immediate low-cost solution for the MTX concept. The Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) program started with a project budget of \$2.3B FY11 (LaGrone 2013) which was eventually scaled down for cost purposes. Some of the requirements set for the Unmanned Combat Aerial System (UCAS), first envisioned with an emphasis on strike missions, were that its unit acquisition cost would not be greater than \$150M, it would be able to strike from a range of at least 2,000 nautical miles, and it would be able to maintain a consistent orbit of 600 nautical miles (LaGrone 2013). Already three years into its testing phase, the UCLASS program is scheduled to award a contract for its development in 2015 (Naval Air Systems Command 2014). Although the initial stages of the development of the X-47B show promise, due to the early stage of the technology involved and the risk of cost overruns if the project is accelerated, the modified UCLASS would best be approached as a follow on program. By utilizing the converted QF-18 platforms, valuable lessons learned can be gathered regarding control schemes and Tactics, Techniques, and Procedures (TTPs), which can then be leveraged to improve the X-47 program.

3. Control Scheme Development

The ability to operate within the A2AD environment requires the development of multiple control schemes to allow the MTX to be both safe and effective. The U.S. Navy already utilizes several robust data links that could be incorporated for use. LINK 16, CEC, and the new NIFC-CA are all options for integration. The potential for jamming and other forms of exploitation require that some form of autonomy be programmed in to allow, at a minimum, the aircraft to safely return to base in the event of a loss of communications or navigation. Control schemes to be investigate include dedicated fighter-to-fighter data-link, as described in Section D.1.b. Further options include satellite-to-ground station data-links, control by E-2D Hawkeye or similar AWACS aircraft, or control by Air Intercept Controller watch-standers onboard AEGIS ships. One

key consideration for remote control is latency. Effort should be expended to ensure that latency is minimized to maximize the offensive capability of the MTX.

4. EMCON Status Limitations

A common concern when operating any unmanned aircraft with U.S. military forces is the ability to operate them at any Emission Control (EMCON) status. If UAVs are to be used consistently from HVUs, such as an aircraft carrier, the need for them to be able to land autonomously when EMCON conditions precluding flight control are set is crucial. Without this capability, there is a possibility of losing airborne UAVs when the ship of origin is required to secure its emissions. Command and control redundancies should be designed into all ship-based UAV platforms including the MTX concept platforms. Alternatively, unmanned aircraft could be diverted to nearby land bases, if available, in the event that EMCON must be set while they are airborne.

F. QUANTIFYING PERFORMANCE: HUGHES SALVO EQUATIONS

In order to measure the added benefits that the MTX would bring to the fight the Hughes Salvo Equation (Hughes 1995) was modified in order to use it in an air-to-air scenario.

The primary variables used in the Hughes Salvo Equations are defined as:

A/B = # of Aircraft in battle

a_1/b_1 = # of missiles fired by each aircraft

(a_1 would originate from Aircraft A; b_1 would originate from Aircraft B)

a_2/b_2 = each individual missile's P_K

a_3/b_3 = Evasion Effectiveness

a_4/b_4 = Countermeasure Effectiveness

The Hughes Salvo Equation used for the purpose of this analysis solves for the number of losses incurred by force A (represented by ΔA) and is arranged in the following manner:

$$\Delta A = (B * b_1 * b_2) - ((A * a_3) + (A * a_4))$$

This equation, and its tactical ramifications, will be explored in depth in the scenario below.

Notes and assumptions on the scenario:

- The U.S. AMRAAM is given a slightly higher P_K of 0.85, while the PRC PL-12s are assigned a P_K of 0.65.
- Each J-10 has one chance to conduct an evasion with a probability of success of 0.2, while each QF-18 has a slightly higher chance at 0.25 as they are diving away. The F-35C has an evasion chance of 0.5, given its higher stealth.
- All countermeasures are assumed to be 10% effective.

1. DCA Scenario Vignette

The scenario takes place in the South China Sea. The PRC is attempting to force a United States Surface Action Group (SAG) away from the Spratly Islands. The Chinese forces, using H-6 bombers capable of multiple ASCM launches, leave Hainan Island and are being escorted by 30 J-10 fighters. Each J-10 is loaded out with six PL-12 BVR air-to-air missiles. Four F-35Cs, carrying six AIM-120s (AMRAAM) each were operating over Palawan originating from a CVN conducting operations in the Sulu Sea. They detect the incoming strike. All airborne fighters are directed to engage the H-6s and J-10s when in sight. Two QF-18s make up the U.S. SAG's DCA stations and there are currently two sets of them employed. Each QF-18 is carrying 10 AIM-120 (AMRAAM) Air-to-Air missiles.

The first aircraft to arrive are the QF-18s. They are being controlled by a DDG in close proximity and quickly launch all of their missiles. Once the PRC fighters realize they are under fire, they immediately launch in retaliation. Each aircraft decides to launch only half of their missiles (three each) while they search for the source of the threat. This scenario is illustrated in Figure 79.



Figure 79. Two DCA stations protecting SAG in South China Sea of two unmanned QF-18s each and F-35s conducting operations over Palawan.

2. Air-to-Air Battle Outcome Based on Hughes Salvo Results

A total of 34 AMRAAM missiles (of the 40 fired) from the four QF-18s find their PRC targets and home in. Each J-10 attempts one evasion while deploying countermeasures, but a total of 26 AMRAAM missiles still destroy their targets, leaving only four J-10s, each with only half of their missiles remaining, to escort the H-6 bomber force onward to weapons release range. All four of the QF-18s are destroyed in the exchange.

Meanwhile, the four F-35Cs utilize their low RCS to close within firing range undetected. They each fire two missiles before evading, leaving the J-10s without targets to fire upon. All the J-10s are destroyed by this salvo, and the F-35Cs close in to finish off the bomber force. The full salvo calculations can be found in Table 18.

In this scenario, a force of H-6 bombers escorted by over 30 PRC fighters was engaged and destroyed by only eight aircraft, of which only half were manned. While not a perfect analogue for an actual air-to-air battle, the modified Hughes Salvo Equations

provide a means to calculate rough approximations of the contributions of additional missiles to an air-to-air battle fought in missile salvos.

30 PLA fighters each with 6 PL-12, 4 mod F/A-18C w/10 AMRAAM ea, then 4 F-35C with 6 AMRAAM each									
	Red	Blue							
Fighters:	30	4				Fighters:	4	4	
Missiles fired, each :	3	10				Missiles fired, each :	3	2	
Total Missiles	90	40				Total Missiles	12	8	
Pk of Missiles:	0.65	0.875	<-----30 J-10s versus 4 QF-18C			Pk of Missiles:	0.65	0.85	
Eff. Missiles	58.5	35				Eff. Missiles	7.8	6.8	<-----Remaining J-10s versus 4 F-35C
Countermeasures employed:	1	1				Countermeasures employed:	1	2	
CM Effectiveness	0.1	0.1				CM Effectiveness	0.1	0.25	
Missiles Distracted	3	0.4				Missiles Distracted	0.4	2	
Evasions attempted:	1	1				Evasions attempted:	1	1	
Evasion success chance:	0.2	0.25				Evasion success chance:	0.2	0.5	
Evasion successes	6	1				Evasion successes	0.8	2	
Total Missiles Missed	9	1.4				Total Missiles Missed	1.2	4	
Missiles hit:	26	57.1				Missiles hit:	5.6	3.8	
Fighters Remaining	4	0				Fighters Remaining	0	0.2	

Table 18. Results from the Hughes Salvo Equations for the air-to-air scenario.

3. Air-to-Air Battle Monte Carlo Analysis

Expanding on the DCA vignette, a Monte Carlo simulation was conducted to evaluate the effectiveness of a single DCA station comprised of two MTX platforms, each armed with 10 AMRAAM missiles. These were confronted by 10 attacking fighter aircraft. The simulation assumes that each MTX is capable of firing all 10 of its missiles, each targeting a single attacking fighter. Each missile was given a 65% probability of kill, which encompasses all missile functions, from rocket motor burn to warhead effectiveness. The adversary aircraft next deploy countermeasures with a 10% chance of successfully distracting a missile, followed by an evasion attempt at 20% effectiveness. Evasion effectiveness is in this case a combination of maneuver, radar cross section, and passive countermeasures. Each event was assigned a binary result, and aircraft survival was determined by simply summing the effective missiles and then subtracting instances of successful countermeasure employment or evasion.

The Monte Carlo was run through 5,500 repetitions. Each missile, evasion attempt, and countermeasure seduction attempt utilized independent randomly generated

numbers. The number of surviving aircraft was tallied following each run, generating the histogram in Figure 80.

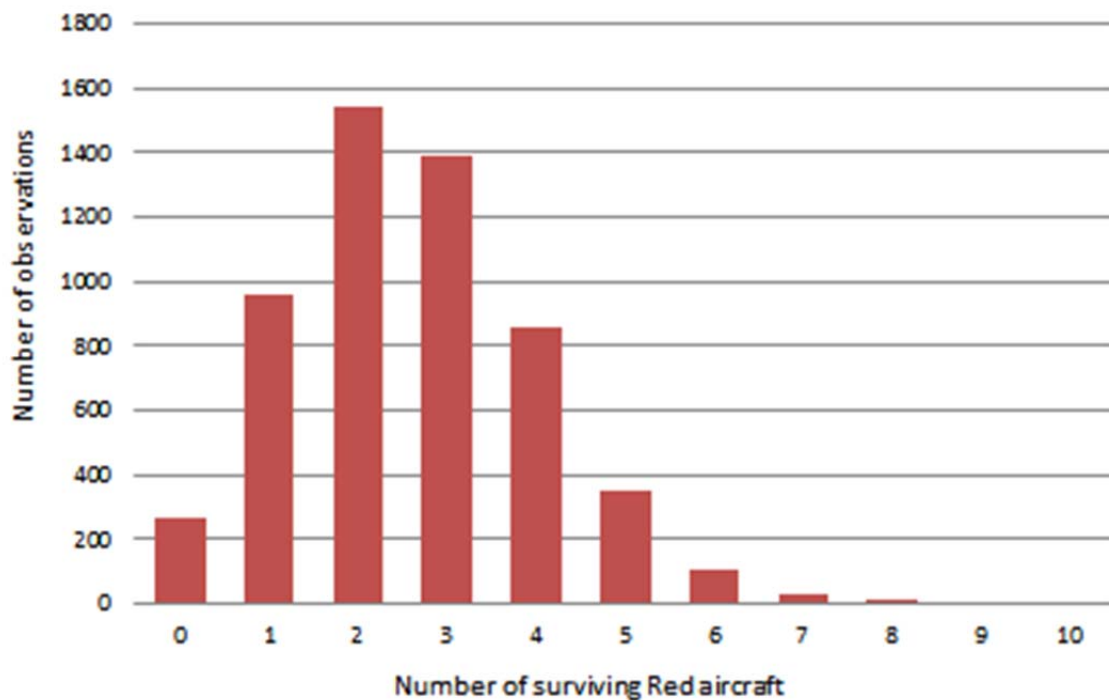


Figure 80. Result of 5,500 runs of MTX Monte Carlo Simulation showing number of survivors

The results show that with the assumptions made, just two MTX platforms, outfitted with 10 AMRAAM missiles, have a 99.9% chance of destroying three aircraft, or approximately one-third, of an incoming raid of 10 aircraft. There is an approximately 97% chance that more than 5 aircraft would be destroyed, and an approximately 75% chance that fully two-thirds of the incoming aircraft would be destroyed. Depending on the adversary's doctrine, destruction of one-third to one-half of an incoming raid would likely cause the surviving aircraft to turn back. Even if it did not, however, there is a strong likelihood that the surviving aircraft would be degraded in their ability to respond to further attack by manned fighters or ground-based air defense systems.

This simulation helps to demonstrate the potential contribution of the MTX to a defensive counter-air scenario. More detailed simulation, using classified figures for the effectiveness of missiles, countermeasures, and evasion would provide more fidelity and

could potentially change the results. Thus, additional modelling and simulation is recommended.

G. MTX CONCEPT RECOMMENDATION

It is recommended that the MTX concept be implemented in two phases. The first phase will be to convert existing manned platforms into unmanned drones. With the successful implementation of the QF-16 as a full scale aerial target, current F/A-18s should be converted into unmanned platforms to serve as Missile-Truck UAVs that help to perform the OCA mission.

If it can keep its long range attributes, the MQ-9 Reaper should be modified to achieve a higher operational ceiling and slightly more weight carrying capacity to perform the DCA and Early Warning missions desired. (U.S. Air Force 2010). However, a more detailed cost analysis of the price to make these modifications could render the platform infeasible depending on the fiscal environment.

To fully realize the utility of the MTX concept for OCA, DCA, and Early Warning missions combined, a flexible platform with a longer range of operation is required. Phase two of the MTX concept introduces a new platform that has a longer endurance and payload to replace the QF-18. The potential new platform for this versatile role should be the Unmanned Combat Air System (UCAS) X47-B. The new platform should be configured into an asset with better endurance, payload, and stealth to enhance the F/A-18s in theater. These design attributes will increase survivability and the probability of mission success.

In addition, it is also recommended that the MTX drone not only be used as a slaved missile-truck for airborne fighters, but also have the capability to be configured to operate remotely from ground stations so that it can be incorporated into the dispersed air wing concept. This would aid in accomplishing the goal of keeping HVUs outside of the DF-21 range without sacrificing mission capabilities when operating within an A2AD environment. The MTX concept has the potential to close the capability gap while addressing the following MOEs of the solution:

Combat Attrition – minimize Blue force loss (See Quantitative Analysis in later section*)

ISR Power – Early Warning; 24 hour “eyes in the sky”; custom sensor suite

Strike Power – increased weapons payload; “UAS enhanced Self Escort Strike” augmented capability

H. CONCLUSION

The concept of the MTX adds three important elements that will aid in closing the capability gaps that are present when the CVN is distant from the fight. First, it reduces risk to personnel by replacing several manned aircraft required to perform the same mission. Second, it increases the payload available to manned fighters allowing the ability to engage more targets. Finally, MTX will provide an increase in combat range by eliminating weight and adding extra fuel tanks.

An unmanned fighter jet (QF/A-18 or QF-16), an upgraded version of the MQ-9 Reaper (MQF-X), and the X-47B UCAS were all investigated as candidates for being converted into a MTX Missile-Truck UAV. Each contender brings its own unique capabilities and characteristics that the team was able to dissect in order to make a recommendation for an appropriate option for future development. Taking into account the unit cost of each aircraft, the availability within the timeline of the scenario, and the capabilities of each platform, the following conclusions were made. A converted unmanned fighter would be the quickest and cheapest solution to fill the OCA capability gap if dispersed air bases are available and within range for landing. The MQF-X would likely require costly modifications, but would fill the dedicated DCA role in protecting high value assets afloat and ashore. And while the X-47B UCAS brings the greater range and endurance that is desirable within the A2AD environment it would come at greater price and longer lead-time for procurement due to the current TRL of the program. Therefore, a phased approach that leverages lessons learned from converted manned fighters first, then applies those lessons to follow-on unmanned aircraft makes sense both fiscally and technically.

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X. FORCE STRUCTURE ANALYSIS OF ALTERNATIVES USING INTEGER LINEAR PROGRAMMING

A. CHAPTER SUMMARY

The South China Sea Basing Optimization Model was developed to prescribe an optimal basing plan and force structure for the Navy by determining the quantity and locations of nuclear powered Aircraft Carriers (CVNs), Light Aircraft Carriers (CVLs), UAV Carriers (Sea Scouts) and Expeditionary Airbases (EABs) to cover specified mission sets in the South China Sea for minimal risk.

Risk is defined to be the probability of mission-kill per day from all enemy weapon systems within reach of the platform or land base weighted by the number of personnel at risk. A mission-kill is defined as any damage suffered which causes flight operations to halt. If flight operations are halted, then the carrier or airfield is rendered ineffective and unable to contribute to the conflict.

CVNs are the largest and most capable assets. They embark a Carrier Air Wing (CVW) consisting of 44 strike/fighter aircraft (Naval Aviation Enterprise 2012). CVLs are smaller, conventionally powered light aircraft carriers that embark up to 16 STOVL strike/fighter aircraft (Weisser and Coles-Cieply 2009). CVLs can perform all of the same missions as a CVN, although at a reduced capacity. Preliminary analysis showed that CVLs were not a component of the optimal force structures and were eliminated from the final recommendations. The reasons for this decision are described in detail in the following sections. The Sea Scout is classified as an escort carrier (CVE). Traditionally, CVEs accompany surface action groups or convoys to provide specific capabilities and defenses. In this case, Sea Scouts can provide ISR and strike capabilities but lack the counter-air capability of the other assets. Finally, EABs are land bases that can accommodate up to six STOVL strike/fighters and can be constructed on any suitable land in allied territory.

The team derived a baseline mission set comprising the minimum capabilities necessary for U.S. forces to achieve victory in the Spratly Islands scenario described earlier in this paper. The optimal solutions for the baseline mission are depicted as the

yellow line in Figure 81. In addition to this baseline, several variations of requirements and capabilities were tested to ensure the stability of solutions. Several distinct force structures emerged as the most promising options. The most robust solutions are shown as the red X's in Figure 81 and their geographic placements are shown in the following figures. Any value for risk less than 100% indicates a reduction in risk from the current force structure of CVNs only.

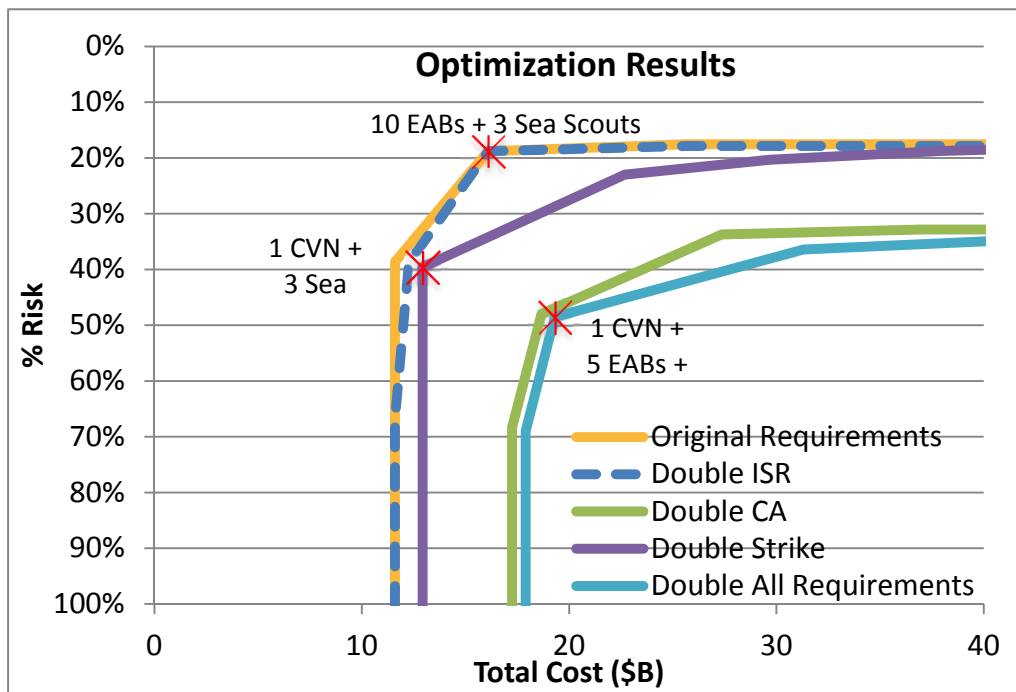


Figure 81. Optimization results.



Figure 82. Alternative 1, one CVN (cyan) with three Sea Scouts (magenta).



Figure 83. Alternative 2, ten EABs (green) with three Sea Scouts (magenta).

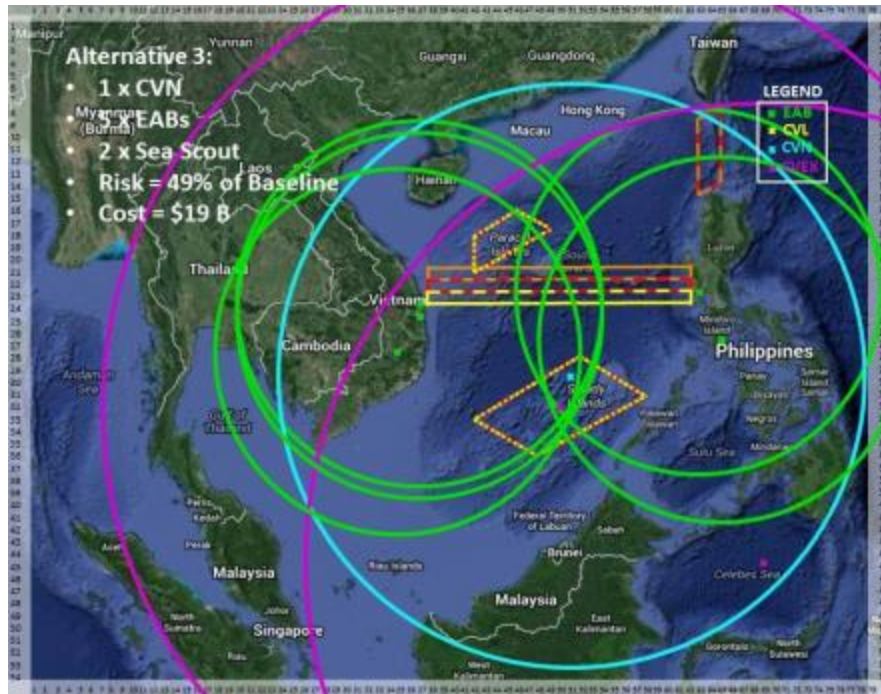


Figure 84. Alternative 3, one CVN (cyan) with five EABs (green) and two Sea Scouts (magenta).

These solutions all meet the minimum baseline requirements and reduce risk substantially from the baseline case of two CVNs operating alone. In addition, they all have sufficient excess capability to meet a doubling of ISR hours required on-station. Of the three solutions, Alternative 2 reduces risk the most, to 19% of the baseline risk. However, if in addition to a doubled ISR requirement, twice as much strike ordnance per day were required, then Alternative 1 could meet those requirements with higher risk level of 40% of baseline. Finally, if all requirements were doubled including twice as many counter-air hours on-station, then Alternative 3 is the best choice despite the higher cost and risk than Alternatives 1 and 2.

From a strategic perspective, the specific quantity of platforms is not as important as the platform types utilized. All three force compositions include the Seas Scout platform and significantly reduce the risk incurred by the baseline force structure of two CVNs.

The Team recommends in the near term that the U.S. Navy actively pursue an unmanned ISR platform to reduce the ISR burden on the current carrier air wing.

Acquiring the Sea Scout or a similar platform is one way to achieve this goal. However, any alternative that efficiently removes ISR requirements would help to reduce overall risk to the fleet.

Additionally, the capability to build and utilize expeditionary air bases could further reduce the risk to the fleet. The Team recommends this as a long-term goal for the U.S. Navy and Marine Corps. EABs provide a scalable alternative to project air power when a full carrier air wing or an additional carrier air wing is not required.

Conventional nuclear powered aircraft carriers need not be eliminated from the force structure, but their massive strike and counter air capabilities should be augmented by additional ISR platforms, and when the entire might of a carrier air wing is overkill, a scalable alternative such as an EAB can bring the force necessary without exposing the fleet to unnecessary risk.

Additional key insights, methods, and results from the optimization model are described in the following sections.

B. INTEGER LINEAR PROGRAMMING (ILP) MODEL: MINIMIZE COST

In order to explore the South China Sea (SCS) scenario, the Team sought a way to compare different force structure alternatives within the context of the scenario. Although many aspects of the scenario are fluid and variable, the geography of the area will always remain constant. This inspired the group to create an Integer Linear Program (ILP) (Rardin 1998) where the geography of the area was translated into fixed nodes for input as a set-cover model. The Team started out with a basic model and continued to add complexity while gaining valuable insights throughout the entire process. Section B describes a basic model and insights gained, and Section C describes the full optimization problem to minimize risk to the force.

For the basic model, the goal of the ILP is to minimize cost subject to a set cover mission constraint. This mission constraint requires that naval air assets cover the entire South China Sea. This requirement includes both time-critical strike missions and quick-reaction counter-air missions to intercept PLA aircraft.

The key insights from the basic analysis are as follows:

1. Key Insights

- A minimum of four expeditionary airbases, three light aircraft carriers (CVLs), or two Ford class carriers (CVNs) optimally placed is required to provide air cover for the entire South China Sea.
- The Philippines and Vietnam offer key basing locations on the east and west sides of the South China Sea. If either of the two countries is removed as a basing ally, the critical areas can no longer be covered with land bases alone. A sea-based carrier is required to fill the gaps.
- Malaysia is the most beneficial basing partner in the southern part of the South China Sea. The two separate sections of the country offer strategic locations on both the east and west sides of the SCS. However, if Malaysia were not available as a basing ally, other countries such as Indonesia, Singapore, and Brunei can fill the void albeit with an increased number of EABs required.
- If CVNs must be kept outside of DF-21D range from Hainan Island, at least two EABs are required to extend air power to the most northern parts of the South China Sea.

2. ILP Formulation: Minimize Cost

Indexed Sets and Subsets

i, j hexagonal regions of South China Sea where j is an alias of i
and $i = \{1, 2, \dots, 4266\}$

k platform type where $k = \{EAB, CVL, CVN\}$

S set of regions i containing water suitable for ships

SA set of platform type k which is classified as a ship where $SA = \{CVL, CVN\}$

L set of regions i containing land suitable for basing an EAB

Q set of regions i which require naval air coverage

Data [Units]

$Cost_k$ fixed cost to acquire and place platform k [\$ Billions]

rad_k the combat radius of an aircraft onboard platform k [nm]

$inrange_{ijk}$ binary data set containing a 1 if the distance from the center of region i to the center of region j is less than rad_k

Decision Variables

X_{ik} binary variable with value 1 if region i is assigned platform k

Objective

$$\min \sum_{i \in L} Cost_{EAB} X_{i,EAB} + \sum_{i \in S, k \in SA} Cost_k X_{ik}$$

There is one objective, to minimize the cost of the force structure.

Subject To

$$\sum_{k \in SA} X_{ik} \leq 1 \quad \forall i \in S \quad (1)$$

Constraint set (1) ensures no more than one ship is placed in each suitable sea region.

$$\sum_{i \in L} inrange_{ij,EAB} X_{i,EAB} + \sum_{i \in S, k \in SA} inrange_{ijk} X_{ik} \geq 1 \quad \forall j \in Q \quad (2)$$

Constraint set (2) ensures at least one base covers each region that requires coverage.

$$X_{ik} \text{ Binary } \forall ik \quad (3)$$

Constraint set (3) declares variables as binary.

3. Data Set Development

To implement the ILP, the South China Sea was first divided into hexagons, each 30 nautical miles in height. This process created 54 rows and 79 columns for a total of 4266 hexagons. The master map can be seen in Figure 85.

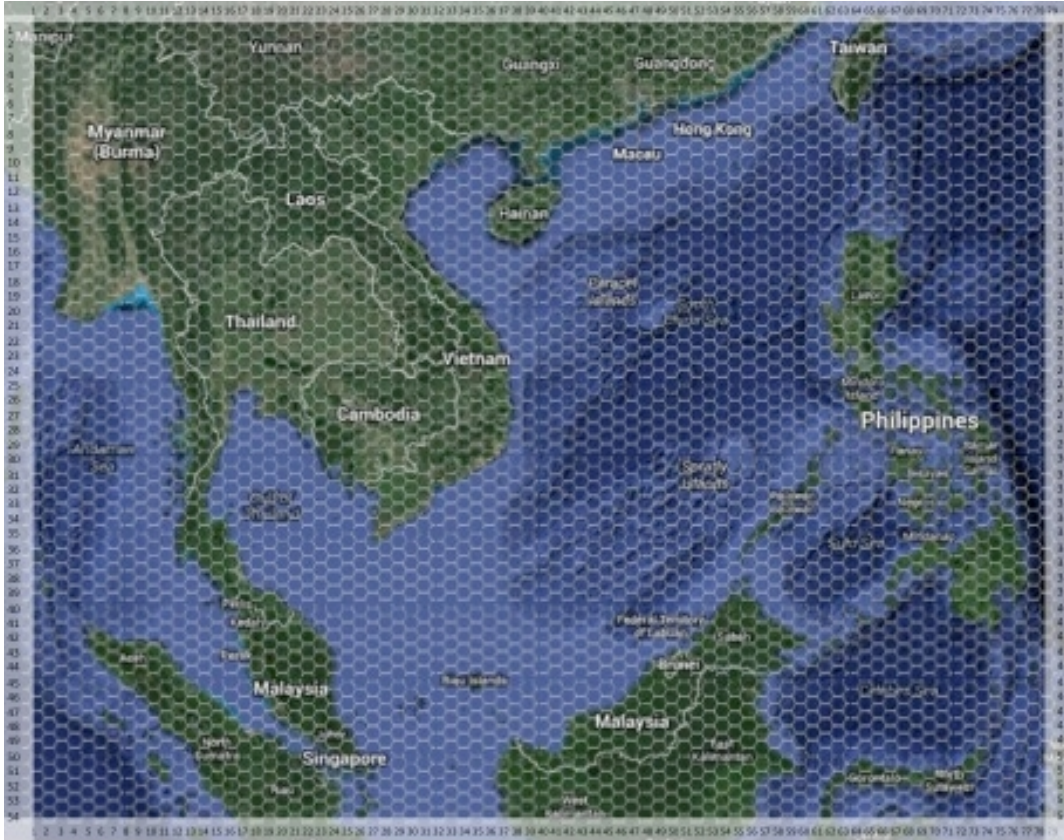


Figure 85. Master map of South China Sea.

Next the geographic region within each hex was classified as either sea or land and by the respective nationality. Finally, the distances from the center of each hex to the center of every other hex were calculated.

Initially, three alternatives were explored for projecting naval air-power in the region:

1. Ford Class Aircraft Carriers (CVNs) operating F-35Cs;
2. Light Aircraft Carriers (CVLs) of about 30,000 tons operating F-35Bs;
3. Expeditionary Airbases (EABs): austere, temporary refueling and arming points, designed for Short Takeoff, Vertical Landing (STOVL) aircraft including F-35Bs and helicopters.

Full-sized airfields, such as Clark Air Base in the Philippines, operating F-35A aircraft are not included in this model. Due to the size and static nature of these bases, they are ideal targets for conventional ballistic missiles. Therefore, to address the possibility that these bases might be put out of action for the critical first stages of a conflict, this model explores other options in the absence of such bases.

Initially Vietnam, Indonesia, Thailand, Malaysia, Singapore, Brunei, and the Philippines are all considered as possible basing allies in the region. Determining specifically which countries will grant expeditionary basing rights to the United States in the year 2025 is beyond the scope of this project. However, using sensitivity analysis to eliminate potential allies one at a time, the team discovered which countries are most vital as basing allies and thus where political efforts in the current timeframe could be reinforced.

The regions of the South China Sea requiring immediate naval air coverage were determined. Those regions can be seen outlined in red in Figure 86. The initial critical region was made intentionally large and encompasses all of the contested regions of the South China Sea. It represents a scenario where the location of the next conflict is completely unknown, but naval forces must be ready to react anywhere. Future iterations will narrow the scope of the coverage to anticipated locations of conflict.

Some assumptions were made in order to facilitate the analysis. These assumptions are:

4. Assumptions

- This scenario takes place in the year 2025. The Navy and Marine Corp are equipped with F-35 aircraft.
- Expeditionary airbases are assumed to be small temporary airstrips capable of operating STOVL (F-35B) aircraft only.
- Each EAB has the same cost of construction regardless of region placement.
- CVLs are light aircraft carriers of around 30,000 tons capable of carrying up to 20 STOVL (F-35B) aircraft.

- The coverage radius of a CVN is considered to be the unrefueled combat radius of the F-35C. This allows for quick reaction time without the logistics and delays associated with aerial refueling.
- Full sized airfields, such as Clark Air Base in the Philippines, operating F-35A are not available to provide the required coverage.
- The combat radius of the F-35B is 450 nm.
- The combat radius of the F-35C is 600 nm.

5. Results

Several different cases were designed to determine the minimum number of bases and their optimum placement to provide the required air coverage. The results can be seen in Table 19.

Case #	Description	Solution		
		EABs	CVLs	CVNs
1	All allies allow EABs	4		
2	No allies allow EABs		3	
3	All allies except Malaysia allow EABs	5		
4	All allies except Vietnam allow EABs	3	1	
5	All allies except the Philippines allow EABs	3	1	
6	No allies allow EABs, No CVLs			2
7	CVNs must be kept outside of DF-21 range, No CVLs	2		2
8	All allies except Malaysia and Indonesia allow EABs	5		

Table 19. Cases evaluated and optimal solutions.



Figure 86. Case 1, all countries allow EAB access.

Case 1 shows that four expeditionary airbases can cover the entire critical region. There are several different locations of bases that could satisfy these requirements, one of which is shown in Figure 86. It utilizes two bases in Malaysia and one base in Vietnam and the Philippines.

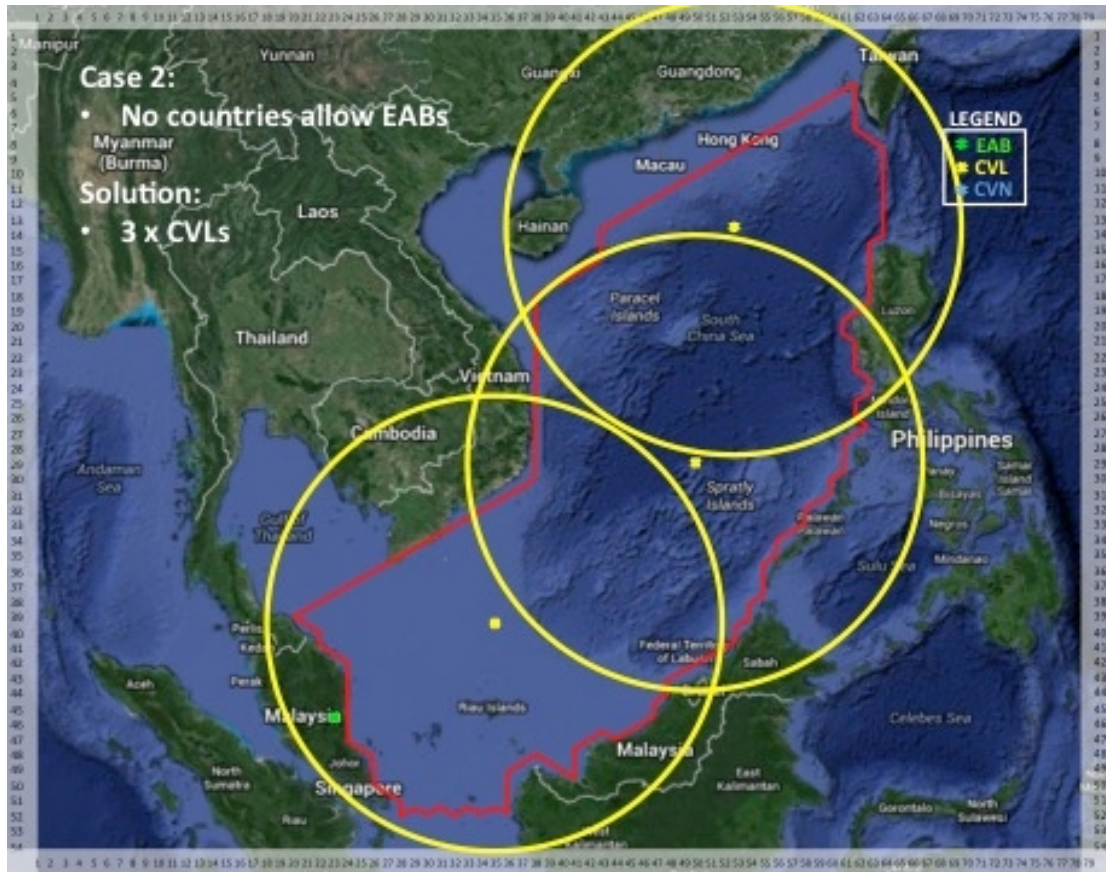


Figure 87. Case 2, no countries allow EAB access.

Case 2 shows that if no countries in the region allowed EAB basing, the region could be covered by three light aircraft carriers, albeit at a higher cost.

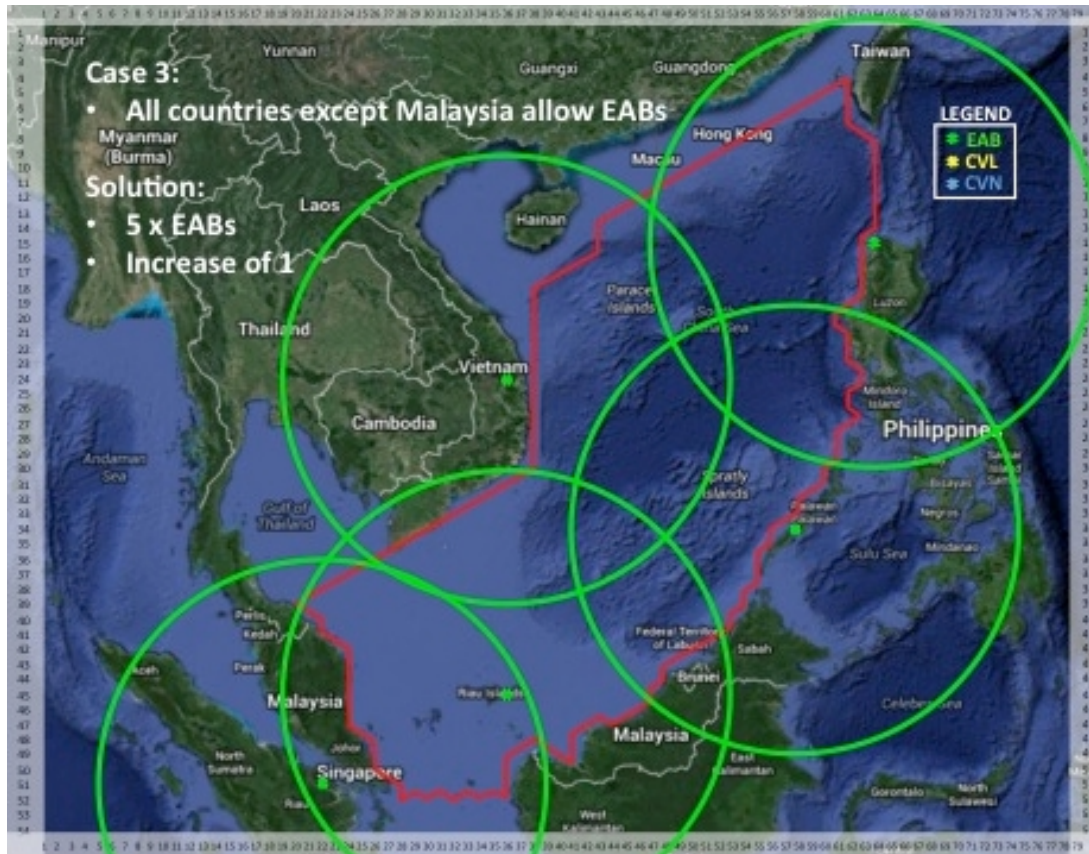


Figure 88. Case 3, all countries except Malaysia allow EAB access.

Case 3 explores the scenario in which Malaysia revokes EAB access. It shows that the region could be covered by five EABs, an increase of one from the original case.

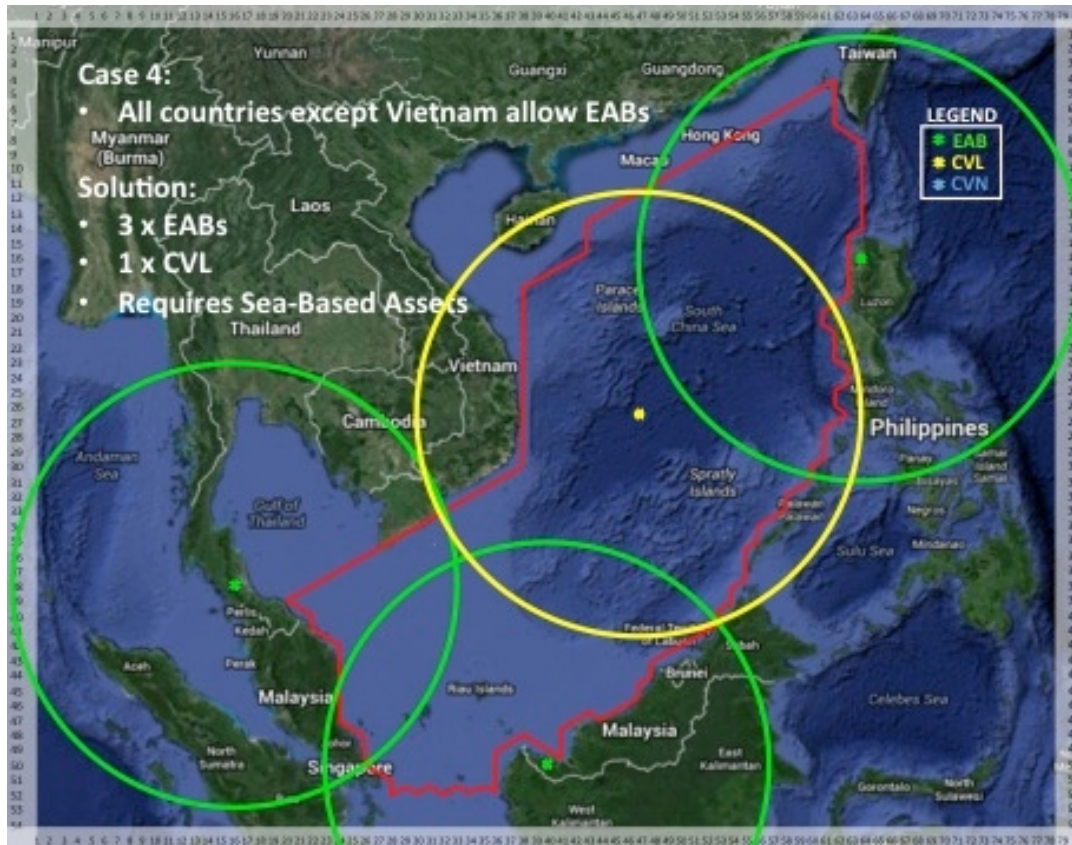


Figure 89. Case 4, all countries except Vietnam allow EAB access.

Case 4 explores the scenario in which Vietnam revokes EAB access. It shows that the region can no longer be covered by EABs only. It requires at least one sea-based platform to meet the requirements. In this case, three EABs and one CVL are the optimal solution.



Figure 90. Case 5, all countries except Philippines allow EAB access.

Case 5 explores the scenario in which the Philippines revoke EAB access. Similar to Vietnam, it shows that the critical region can no longer be covered by EABs only. It requires at least one sea-based platform to meet the requirements. In this case, three EABs and one CVL are the optimal solution.



Figure 91. Case 6, no EABs and no CVLs.

Case 6 shows that using only traditional carrier strike groups consisting of CVNs, the critical region could be covered by two aircraft carriers.

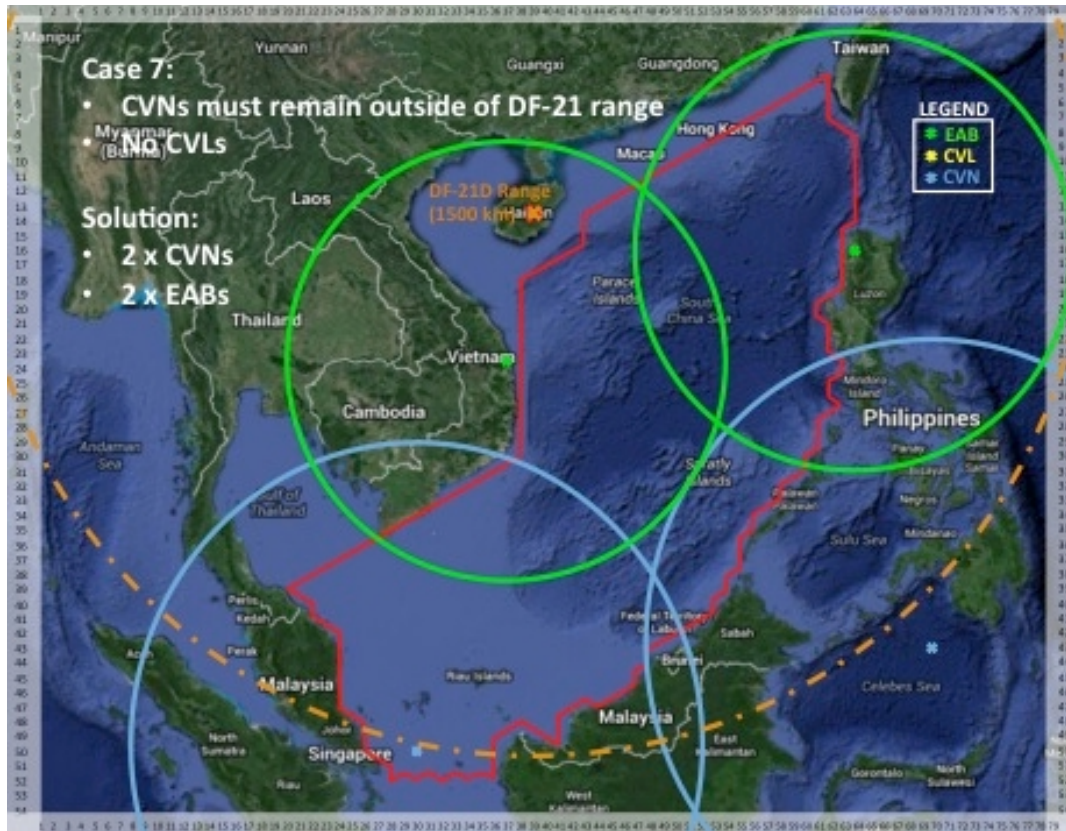


Figure 92. Case 7, no CVLs, and CVNs must remain outside of DF-21 range.

Case 7 explores the case where CVNs are required to operate outside of DF-21 range due to strategic directives. This case requires two EABs in addition to two CVNs to cover the entire region.



Figure 93. Case 8, all countries except Malaysia and Indonesia allow EABs

Case 8 explores the case where both Malaysia and Indonesia do not allow EAB access. The solution shows that this loss does not have significant adverse effects. The continued access allowed by more traditional U.S. allies such as Singapore and Brunei allow for the full region to be covered with a total of five EABs.

C. INTEGER LINEAR PROGRAMING (ILP) MODEL: MINIMIZE RISK

After analyzing the basic set-cover model, the Team sought to gain more insight by adding realism and complexity. The goal of this enhanced ILP is to minimize the risk to friendly forces subject to satisfying three types of mission requirements. The three mission types for this model are strike, counter-air, and ISR. For this scenario, specific mission requirements are assigned to each region on the map. It is assumed that if these mission requirements can be met by the force structure, then the operational commander has all the tools necessary to enable victory.

One important distinction should be made here. This is not intended to be a scheduling problem. This means the model does not specify exactly when or where each capability will be used, but it provides the commander with an overall quantity of each capability to distribute as he/she sees fit. For example, one requirement calls for 500,000lbs of strike ordnance to be available in the region of the Spratly Islands each day. This does not specify locations and types of targets, but enables the commander to distribute the strikes as the circumstances require.

To implement this model, four different data sets were created for each alternative. These four data sets are risk, strike effectiveness, counter-air effectiveness, and ISR effectiveness.

Risk is defined to be the probability of mission-kill per day from all enemy weapon systems within reach of the platform or land base weighted by the number of personnel at risk. A mission-kill is defined as any damage suffered which causes flight operations to halt. If flight operations are halted, then the carrier or airfield is rendered ineffective and unable to contribute to the conflict.

Each mission set is quantified by a specific measure of effectiveness. These MOEs are described fully in Chapter VI Section B and shown below.

$$\textit{Strike Power} = \textit{Assets} \times \textit{Payload} \times \textit{Mission Success Rate} \times \textit{SGR}$$

$$\textit{Counter Air Power} = \textit{Assets} \times \textit{RCP} \times \textit{On Station Time} \times \textit{Mission Success Rate} \times \textit{SGR}$$

$$\textit{ISR Power} = \textit{Assets} \times \textit{On Station Time} \times \textit{Mission Success Rate} \times \textit{SGR}$$

Both Sortie Generation Rate (SGR) and on-station vary as a function of range and decrease the farther away from the conflict one operates. Therefore, the ILP can optimize the range and quantities of the various force structure alternatives to determine the optimal number and location of assets.

1. Key Insights

Several key insights were learned from this model.

- Risk to the Fleet can be significantly reduced by fulfilling the mission ISR requirements with Sea Scout or another similar ISR platform
- EABs offer a scalable alternative to a full carrier air wing
- A combination of CVNs, EABs, and Sea Scouts provide a robust solution that can handle a doubling of any or all mission requirements
- Sea Scouts are still a viable alternative even without Hummingbird UAVs
- To utilize EABs effectively, it is necessary to strengthen relationships with Vietnam and the Philippines to ensure basing access for future conflicts

2. ILP Formulation: Minimize Risk

Indexed Sets and Subsets

i, j hexagonal regions of South China Sea where j is an alias of i

and $i = \{1, 2, \dots, 4266\}$

k platform type where $k = \{EAB, CVL, CVN, CVEX\}$

S set of regions i containing water suitable for ships

SA set of platform type k which is classified as a ship

where $SA = \{CVL, CVN, CVEX\}$

L set of regions i containing land suitable for basing an EAB

Data [Units]

$ISRreq_i$ ISR coverage required in region i [hrs/day]

$STRIKEreq_i$ strike capability required in region i [lbs/day]

$DCAreq_i$ counter air coverage required in region i [hrs/day]

$RISK_{ik}$	risk incurred by platform k in region i [probability of mission kill/day]
isr_{ijk}	ISR coverage provided by platform k from region i to region j [hrs/day]
$strike_{ijk}$	strike capability provided by platform k from region i to region j [lbs/day]
dca_{ijk}	counter-air coverage provided by platform k from region i to region j [hrs/day]
$Cost_k$	fixed cost to acquire and place platform k [\$ Billions]
$Crew_k$	personnel required to operate platform k [# of personnel]
$TotalCost$	total budget allowed [\$ Billions]

Decision Variables

X_{ik} binary variable with value 1 if region i is assigned asset k

Objective

$$\min \sum_{i \in L} risk_{i,EAB} Crew_{EAB} X_{i,EAB} + \sum_{i \in S, k \in SA} risk_{ik} Crew_k X_{ik}$$

There is one objective, to minimize the risk to the force structure. The risk is the probability of mission kill of each platform weighted by the number of personnel onboard.

Subject To

$$\sum_{k \in SA} X_{ik} \leq 1 \quad \forall i \in S \quad (1)$$

Constraint set (1) ensures no more than one ship is placed in each suitable sea region.

$$\sum_{i \in L} Cost_{EAB} X_{i,EAB} + \sum_{i \in S, k \in SA} Cost_k X_{ik} \leq TotalCost \quad (2)$$

Constraint set (2) restricts total cost of all the platforms to less than the total budget.

$$\sum_{i \in L} isr_{ij,EAB} X_{i,EAB} + \sum_{i \in S, k \in SA} isr_{ijk} X_{ik} \geq ISRreq_j \quad \forall j \quad (3)$$

Constraint set (3) ensures that the ISR requirement is met in each region.

$$\sum_{i \in L} strike_{ij,EAB} X_{i,EAB} + \sum_{i \in S, k \in SA} strike_{ijk} X_{ik} \geq STRIKEreq_j \quad \forall j \quad (4)$$

Constraint set (4) ensures that the strike requirement is met in each region.

$$\sum_{i \in L} dca_{ij,EAB} X_{i,EAB} + \sum_{i \in S, k \in SA} dca_{ijk} X_{ik} \geq DCAREq_j \quad \forall j \quad (5)$$

Constraint set (5) ensures that the counter-air requirement is met in each region.

$$X_{ik} \quad \text{Binary} \quad \forall ik \quad (6)$$

Constraint set (6) declares variables as binary.

3. Risk Data Set Development

To quantify risk, a measure of effectiveness was created called “Scaled Risk.” Scaled risk incorporates two separate and distinct types of risk that combine for an overall measure of risk. The first type of risk is operational risk. This is quantified by the probability of an asset suffering a mission-kill. For these purposes, a mission-kill is defined as any damage suffered which causes flight operations to halt. If flight operations are halted, then the carrier or airfield is rendered ineffective. The methods used to determine the probability of mission-kill, denoted Pmk, for each option will be discussed in the following sections. The plot of the probability of mission-kill vs. range for each option can be seen in Figure 94.

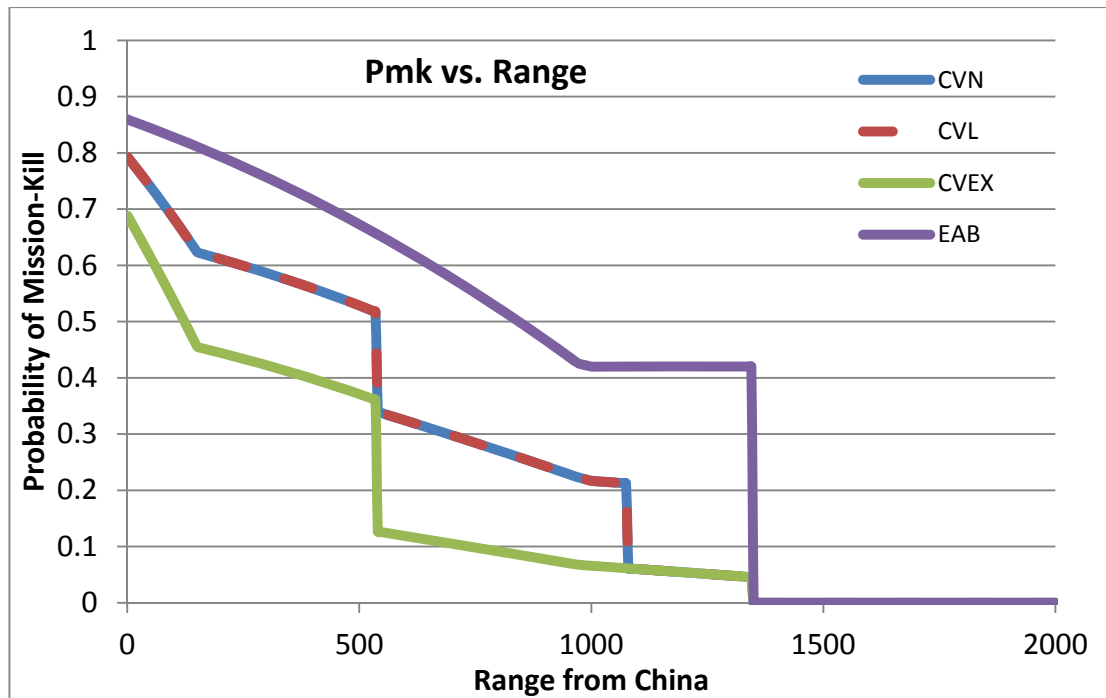


Figure 94. Probability of mission-kill vs. range.

The second type of risk is strategic risk. This type of risk quantifies the emotional, psychological, and political importance of the asset. It's clear that the loss of aircraft carrier would be much worse than the loss of an EAB. Therefore, the operational risk must be scaled by a factor to weight the asset's importance. There is no standard way to measure the importance of an asset. Therefore, for this analysis the team decided to use "number of personnel at risk" as a scaling factor. This includes all crew onboard the ships and any personnel physically located at an EAB. This does not include support personnel physically located away from the conflict such as depot level maintenance or off-site UAV operators. The personnel at risk for each asset can be seen in Table 20. Scaling risk by the amount of personnel at risk does not imply that a mission-kill will cause the fatalities of all personnel, but is used simply as a gauge for the relative importance of the assets.

Option	Personnel at Risk
EAB	100
Sea Scout	150
CVL	940 (Carrasco 2009)
CVN	4450 (IHS Jane's 2013)

Table 20. Personnel at risk

The resulting scaled risk vs. range plots for each option can be seen below in Figure 95. It can be seen that a CVN has a much higher scaled risk than all of the other platforms. This is due to the large size of the crew onboard the CVN and thus the high importance of the asset. However, along with the higher risk a CVN projects a much larger force into the region. A balance must be reached between the risk incurred and the power projected.

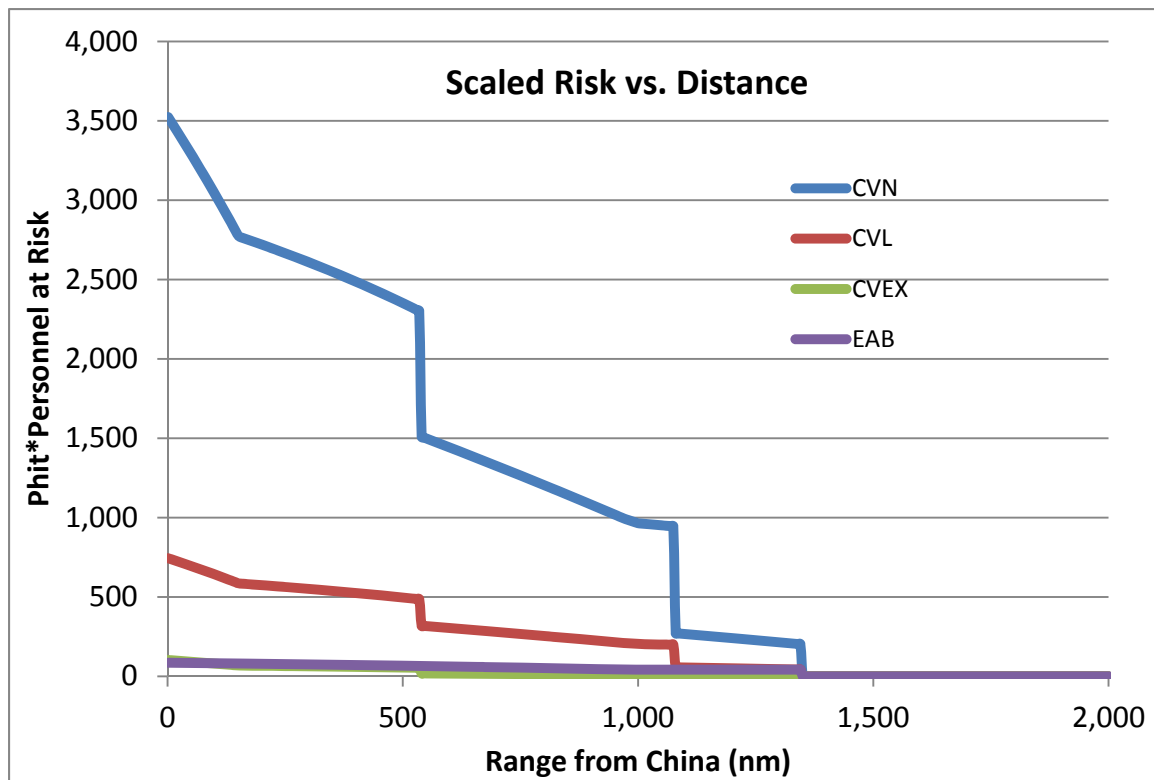


Figure 95. Scaled risk vs. range.

a. CVN/CVL Probability of Mission-Kill

A2AD threats to an aircraft carrier in the South China Sea include submarines, sea mines, anti-ship ballistic missiles (ASBMs), and anti-ship cruise missiles (ASCMs), which can be launched from shore or carried by bombers. It is assumed for this analysis that CVLs will encounter the same threats at the same rates as CVNs. The higher difficulty of targeting and hitting a smaller target with ballistic missiles is offset by the reduced BMD defensive ability of the CVL. Therefore, the CVL risk profile is identical to the CVN risk profile.

The differing ranges and effectiveness of each of the A2AD threats led to the creation of a layered model with each threat composing a separate layer of risk. Each threat is assumed to be independent of the others. These threats to a CVN can be seen in Figure 96.

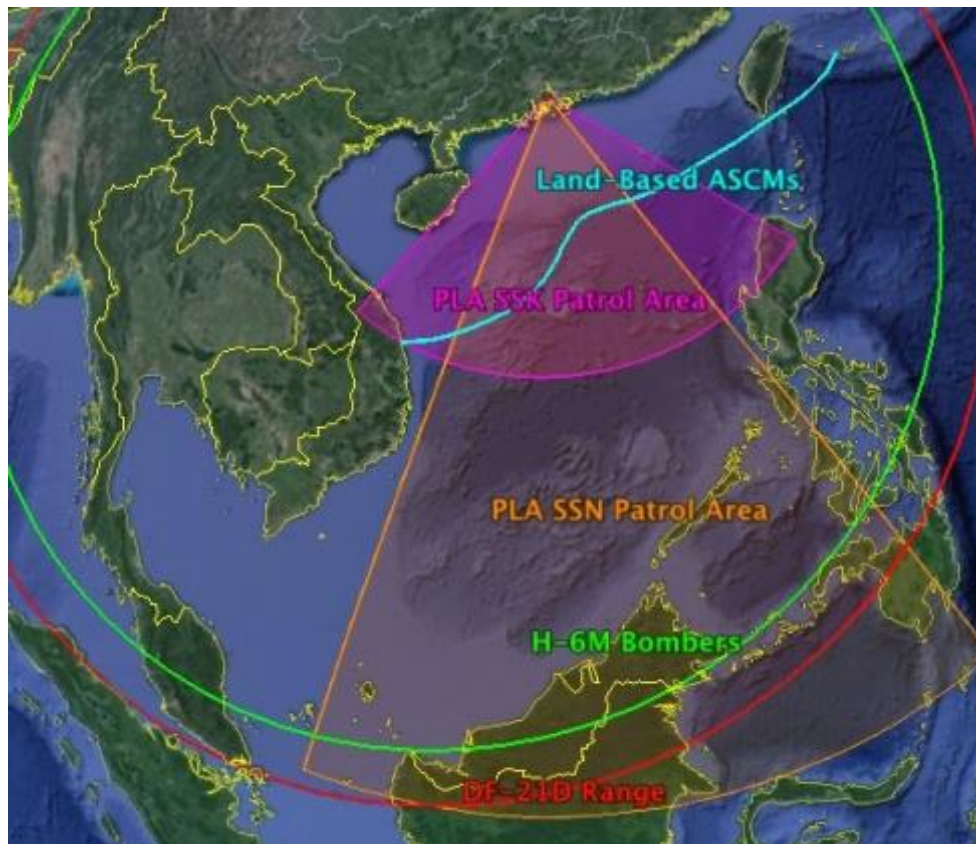


Figure 96. A2AD layered threats.

Due to the nature of the scenario and the desire of both sides to control the contested region and its resources, it is assumed that neither side will employ mine warfare in the area of interest. This does not exclude mine warfare for the entire conflict, but only in the contested waters that will be used by USN ships.

This section describes the risk to a CVN or CVL in the A2AD environment. The risk to a Sea Scout is similar with the exception that it is too small to be targeted by ballistic missiles. Sea Scout risk will be discussed in the next section.

In order to quantify the risk to a CVN, it was assumed that one hit by a ballistic missile, a cruise missile, or a torpedo would likely cause the aircraft carrier to halt flight operations, thus resulting in a mission-kill. This does not imply that one hit is enough to sink a carrier, only to render it ineffective.

Next, each layer of risk is quantified and their effects compiled.

Bombers

China's bomber fleet consists of H-6 bombers capable of aerial refueling that have an effective range of 1800 km (IHS Jane's 2014). Each of bombers can carry four ASCMs that can be air launched at maritime targets (IHS Jane's 2014). The probability of hit (Phit) of an ASCM is assumed to be a constant value of 0.4. This takes into account both active and passive countermeasures used by the defending ships. Using a binomial distribution, if a bomber launches all four ASCMs the probability of one or more hits is 0.87. However, the likelihood of a bomber successfully reaching its launch point is assumed to decrease linearly with range from a maximum achievable value of 0.1. The low value given here is attributed to the defenseless nature of bombers against air-to-air fighters and surface-to-air missiles on unescorted missions. The longer the time a bomber spends in the air, the greater the chance that it will be shot down. A graphical depiction of the individual threat profiles can be seen in Figure 97.

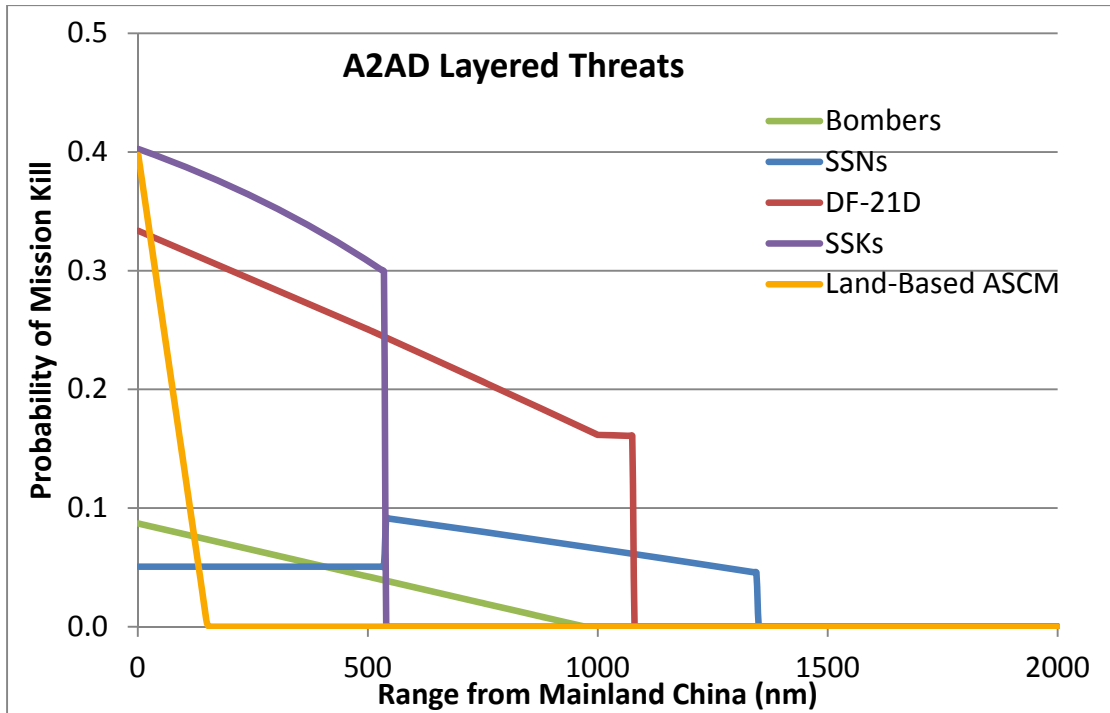


Figure 97. A2AD layered threat profiles.

Submarines

Submarines are the next threat encountered by a CVN. China possesses two general types of submarines: diesel powered submarines (SSKs) and nuclear powered submarines (SSNs). SSKs are assumed to patrol out to 1000km. SSNs are assumed to patrol between 1000 km and 2000 km. China is estimated to possess 30 SSKs and 10 SSNs for this conflict.

The submarine threats were modeled using random search theory. Each submarine was given an equal portion of the operating area to search for 24 hours. When the carrier is detected, the submarine will engage with torpedoes if it can get close enough (this is assumed to occur 30% of the time), otherwise it will engage with ASCMs from a longer distance (this occurs the remaining 70% of the time). Torpedoes have a probability of hit of 0.8. The CVN's risk from submarines also includes the time spent transiting to the area of operations through submarine infested waters.

ASBMs

Anti-ship ballistic missiles are the most uncertain of potential threats. China has developed the DF-21D medium-range ballistic missile. It has a range of 2000 km and a maneuverable re-entry warhead (IHS Jane's 2014). This allows it to target a moving ship such as a CVN. The probability of hit of the missile and tactics employed by the PLA are entirely unknown, but they have been assumed based on unclassified sources and analogous systems. It is assumed that the PLA will launch a salvo of 20 ASBMs each of which has a Phit of 0.5. Given a carrier with sufficient escorts to launch one SM-3 midcourse interceptor (Phit 0.55) and two SM-T terminal interceptors (Phit 0.6), the overall probability of at least one DF-21 striking the carrier is approximately 0.5. This salvo Phit is assumed constant regardless of range. However, in order to launch a salvo, accurate targeting information must be provided.

Targeting for ASBM attacks can be provided by satellites, UAVs, or maritime surveillance ships (“tattle-tale ships”) (Easton 2014) scattered throughout the region. Although China possesses extremely long-range over-the-horizon radar, it is assumed that this technology does not have the required resolution to provide accurate targeting for ballistic missiles.

Satellites are the preferred method of targeting since they work equally well at any range. For the purpose of this analysis the probability of detection was assumed to be 0.3. However, a full sensitivity analysis was performed on this parameter to identify its effects. This can be seen in Figure 100.

The PLA is projected to have UAVs capable of accurate targeting by the year 2025 (Office of the Secretary of Defense 2013). These UAVs are assumed to have a max range of 1000 nm and a max probability of detection (Pd) of 0.5 that decreases linearly to 0 at maximum range. This decrease is due to a combination of fewer hours on station at longer ranges and counter UAV weapons such as SAMs and aircraft.

Finally, maritime surveillance ships consist of both specially outfitted surveillance vessels as well as disguised fishing junks capable of passing along location data. It is assumed that this method has a maximum Pd of 0.05 within 500 nm of shore then decreases linearly to 0 at maximum range of 2000 nm.

Combining the Phit of a salvo of DF-21s with the probability of being accurately targeted by any method gives the overall probability of mission-kill for ASBMs.

Land-Based ASCM

Finally, the last threat posed to a carrier is land-based ASCMs. They have a maximum range of 280 km (IHS Jane's 2014) and a max Phit of 0.4. It is assumed that the Phit decreases linearly to 0 at maximum range due to the counter detection and interception capability of the carrier strike group.

Risk Summary

Each of the individual threat profiles can be seen in Figure 97. Each layer is then compiled to form an overall probability of mission-kill as a function of distance from Mainland China, which can be seen in Figure 98.

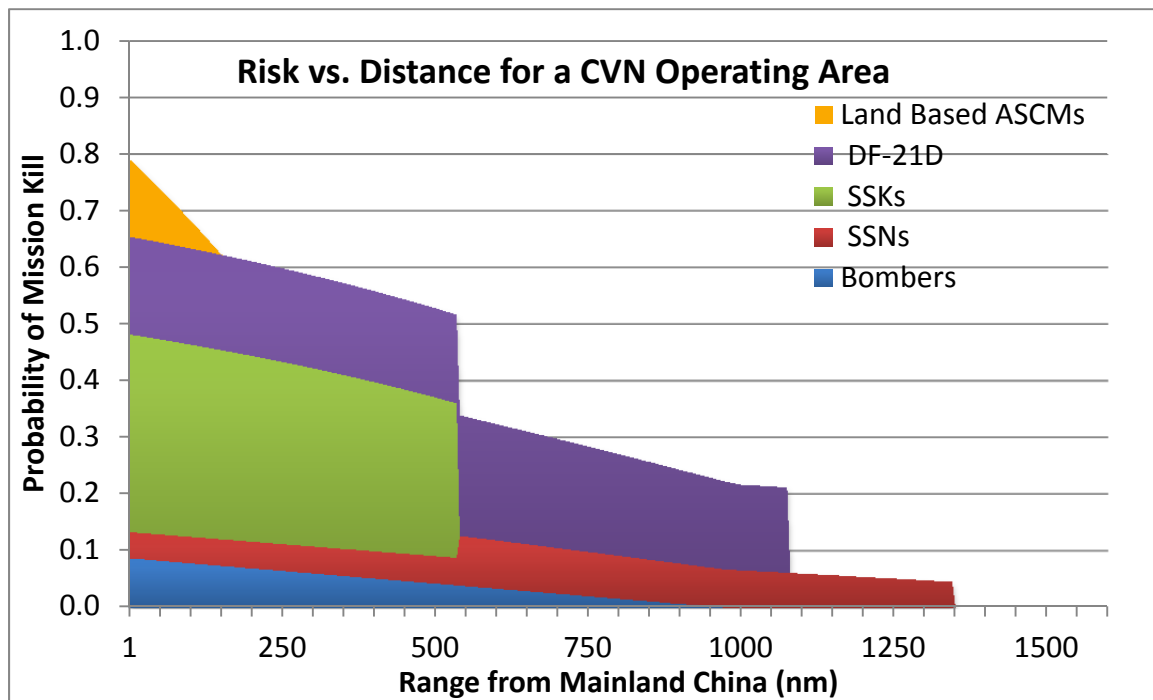


Figure 98. Risk vs. distance for a CVN operating area

Risk significantly increases as the CVN operates closer to Mainland China. Several large increases occur when CVN enters DF-21 range and SSK range. Optimal placement may lie just prior to large step increases.

Sensitivity Analysis

Since the exact probability of hit for a salvo of DF-21 missiles may vary from the original estimate of Probability of mission-kill (Pmk) 0.5, a full sensitivity analysis was performed on that parameter. Pmk was varied from 0.1 to 0.9 and the resultant risk profiles can be seen in Figure 99. The risk to a CVN varies considerably based on the effectiveness of ASBMs.

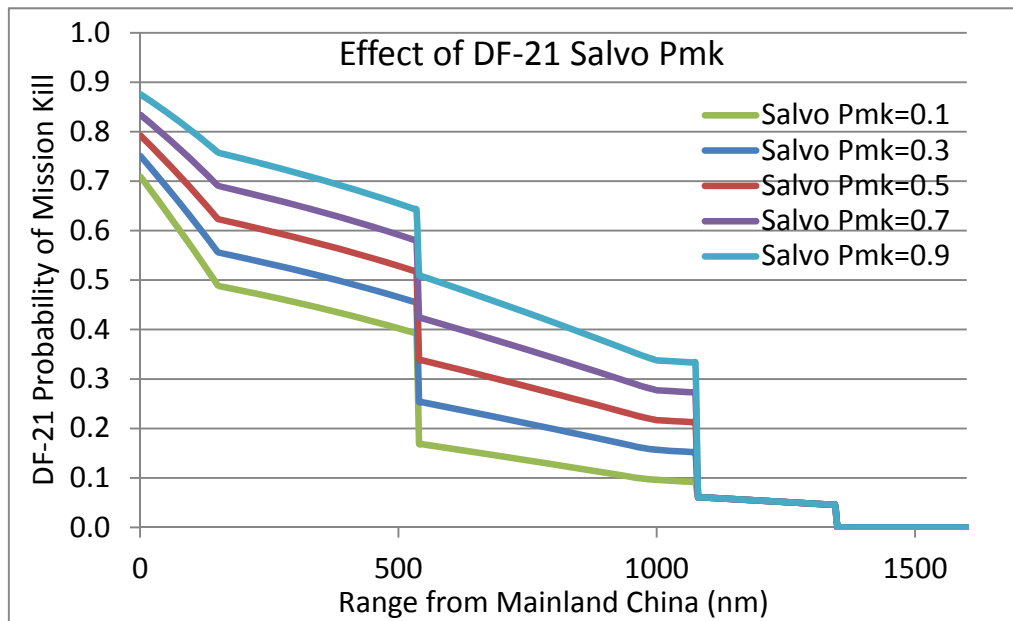


Figure 99. Effect of DF-21 salvo Pmk

Similarly, the exact probability of detection from a PLA satellite may vary from the original estimate of 0.3, so a full sensitivity analysis was performed on that parameter. It was varied from 0.1 to 0.9 and the resultant risk profiles can be seen in Figure 99.

Satellite probability of detection has a very similar effect on risk as ASBM salvo Pmk. Therefore, degrading Chinese satellites could greatly enhance the survivability of a CVN for potentially a much lower cost than additional ballistic missile defense platforms, as seen in Figure 100.

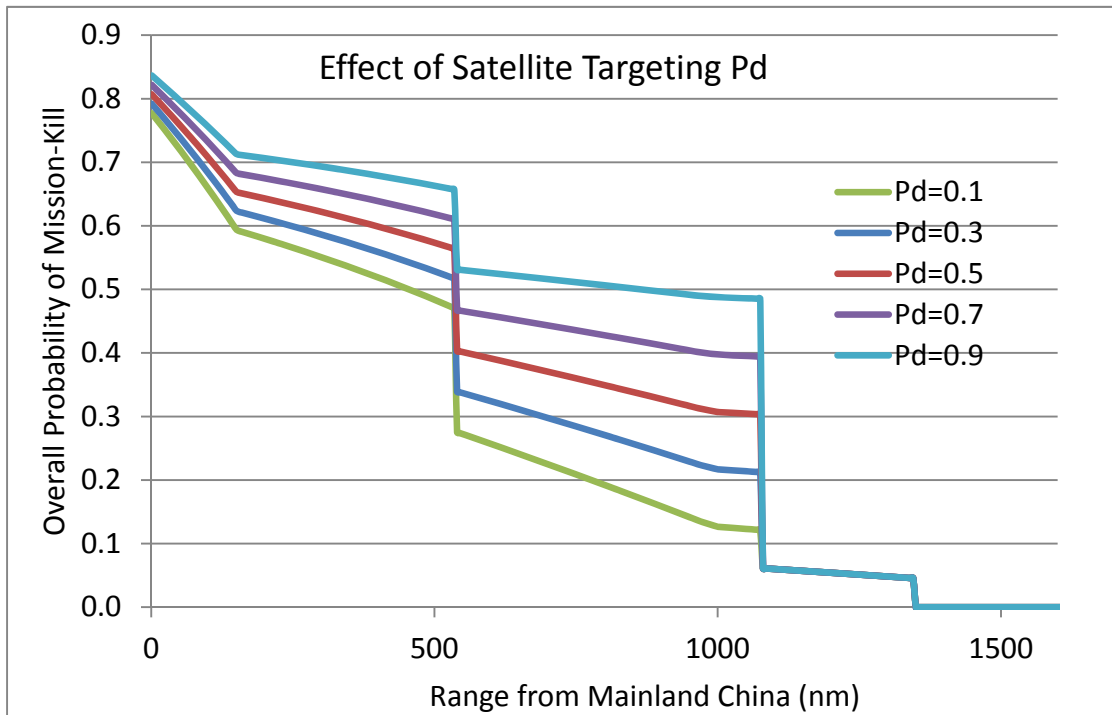


Figure 100. Effect of satellite targeting Pd

Finally, if operating outside of DF-21 range is U.S. preferred tactic, then the most dangerous COA for China is to have SSNs patrol only outside of DF-21 range. At 1200 nm, this increases the probability of mission-kill from 5% to 10%. This effect can be seen in Figure 101.

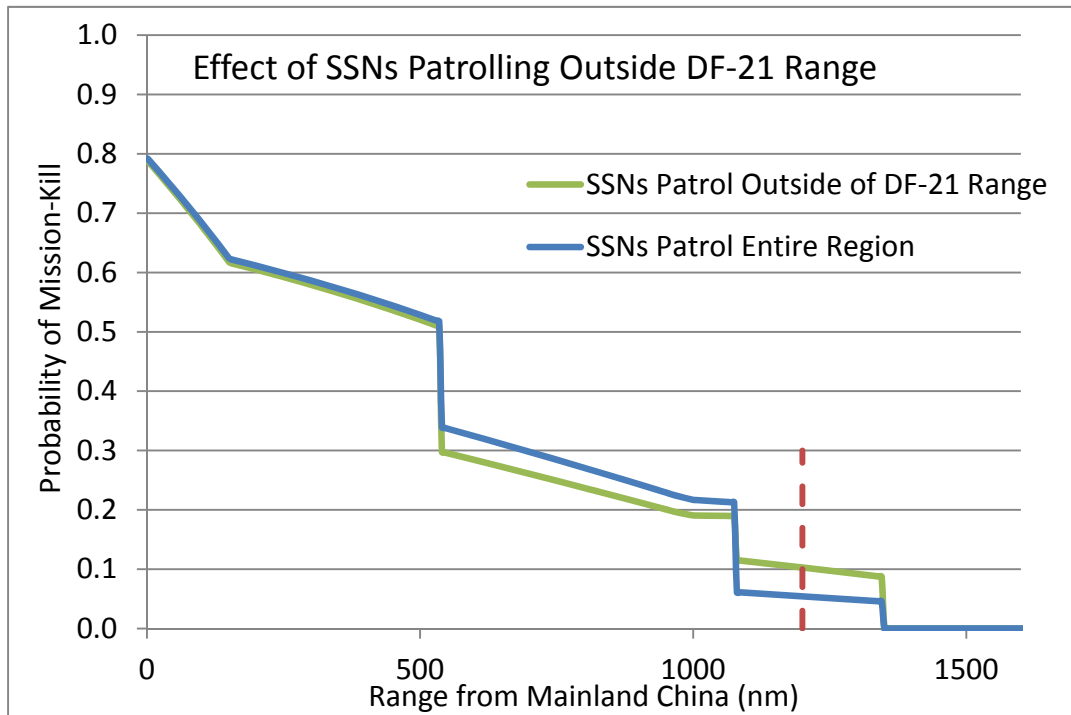


Figure 101. Effect of SSNs patrolling outside of DF-21 range.

b. Sea Scout Probability of Mission Kill

The risks faced by a Sea Scout are identical to the risks faced by a CVN with one exception: they are unable to be targeted by ballistic missiles. This assumption was made because of the smaller size and maneuverability of the Sea Scout platform. Additionally, having a limited supply of DF-21 missiles, it is assumed that China would not attempt to use a significant number against a lower priority target such as the Sea Scout. The resulting risk plot for Sea Scout can be seen in Figure 102.

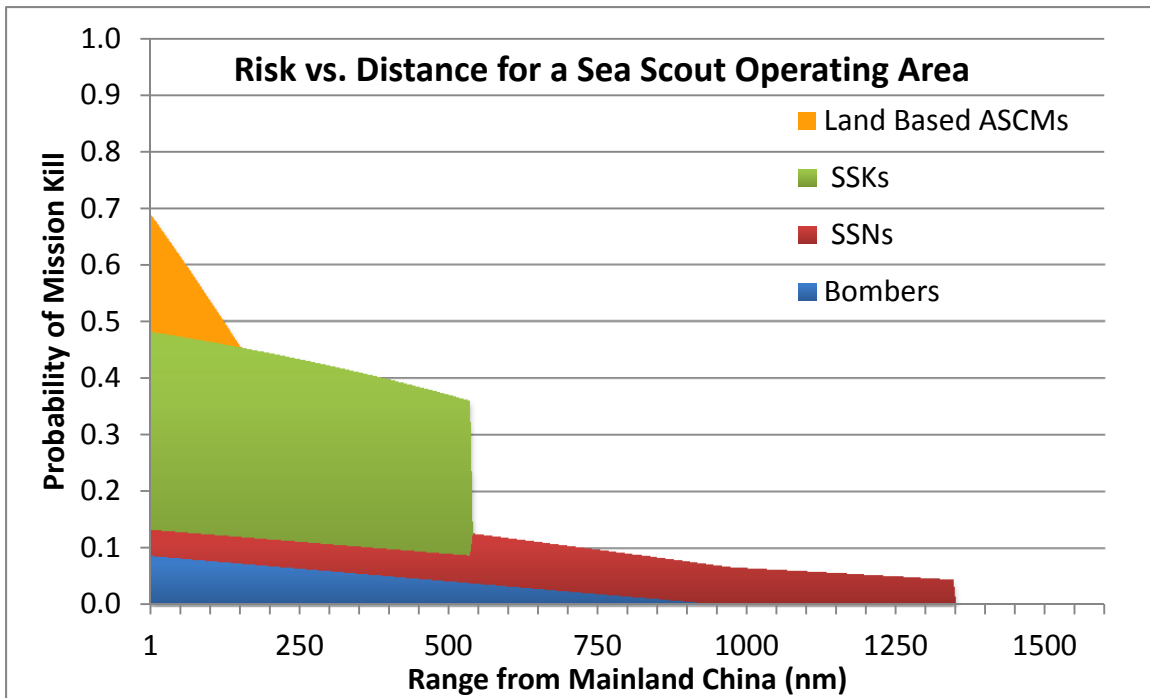


Figure 102. Risk vs. distance for Sea Scout operating area.

c. EAB Probability of Mission Kill

Expeditionary air bases face fewer threats than sea-based platforms. The two main threats to EABs are short-range ballistic missiles (SRBMs) and cruise missiles. China has a very large number of older, nearly obsolete SRBMs, such as the DF-4, that are very inaccurate. The CEP is estimated to be 1500m (IHS Jane's 2013). Although these missiles could be used effectively to disrupt operations at extremely large targets like fixed airbases where precision is not paramount, it is assumed that these older missiles would not be used against small EABs. Therefore, the SRBM threat to EABs is the newer DF-

21C missiles with a much more precise warhead. They have an effective range of 2500km (IHS Jane's 2013). The targeting for SRBMs can come from satellites, UAVs, or HUMINT. It is assumed that satellites have a 0.5 probability of detection of EABs. UAVs have a Pd of 0.5 that decreases linearly out to its maximum range of 1000 km. Probability of detection by HUMINT sources is 0.05.

Land Attack Cruise Missiles (LACMs) such as the C-602 have significantly longer ranges than anti-ship cruise missiles. The C-602 has a maximum range of 1800km (IHS Jane's 2014). It is assumed that the Phit of the C-602 is 0.6 and decreases linearly to 0 at its maximum range. These LACMs can be launched from road mobile launchers mounted on trucks, or alternatively they can be air-launched from bombers. The H-6K can carry seven C-602s (IHS Jane's 2014) out to its maximum range of 1800km. Similar to the previous section it is assumed that the chance of bombers launching their missiles is 0.1 decreasing linearly to 0 at their maximum range. This decrease is due to longer time for detection and intercept by friendly forces. The resultant risk vs. range plot for EABs can be seen in Figure 103.

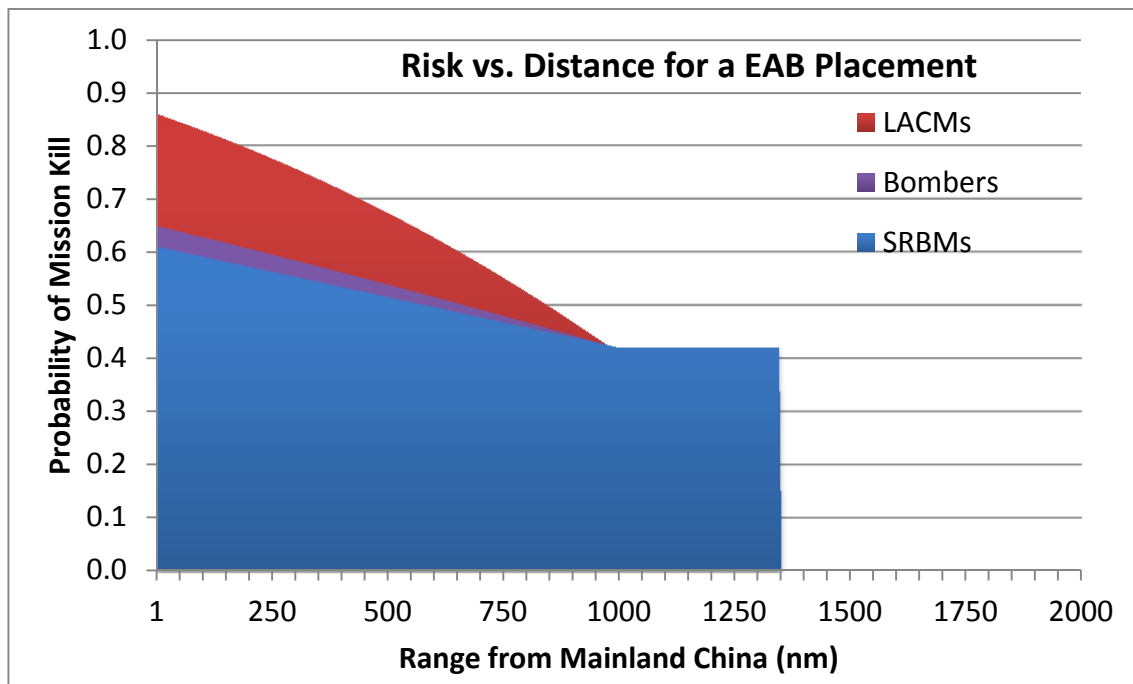


Figure 103. Risk vs. distance for EAB placement.

4. Strike Data Set Development

The next step of this analysis was to model strike effectiveness as a function of range from the conflict. The measure of strike effectiveness is:

$$\text{Strike Power} = \text{Assets} \times \text{Payload} \times \text{Mission Success Rate} \times \text{SGR}$$

Assets are the number of mission capable strike fighters available. Payload is the amount of ordnance, measured in pounds, available on each strike mission. Mission success rate is the probability of a strike mission accomplishing the mission without aborts for maintenance, weather, etc. SGR is sortie generation rate. It is a function of maintenance time (MT), flight time (FT), and turn-around-time (TAT) (Jewell 1998).

$$\text{SGR} = \frac{24\text{hrs}}{\text{FT} + \text{MT} + \text{TAT}}$$

Distance to the conflict directly affects SGR. A greater distance means longer flight time, longer maintenance time, and thus fewer sorties per day.

A graph of each option's strike power vs. distance can be seen in Figure 104. Each of the specific options will be discussed in more detail in the following sections.

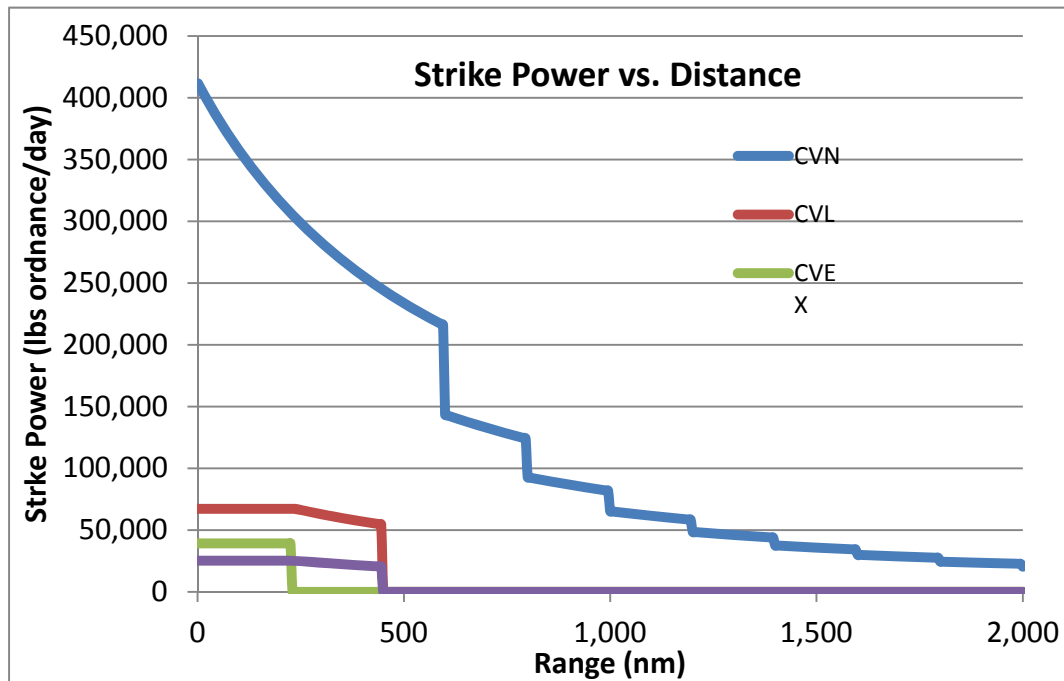


Figure 104. Strike power vs. distance for all options.

a. CVN Strike Power

Current budgets call for 44 strike/fighters in each carrier air wing including a combination of F/A-18s and F-35Cs (Naval Aviation Enterprise 2012). This total is reduced by the percentage of aircraft that are not mission-capable and require maintenance. Seventy-five percent of the aircraft are assumed to be mission-capable at any given time (Jewell 1998). Additionally, six F/A-18s must be equipped as organic tankers for launch and recovery operations. When equipped as tankers, these aircraft cannot perform strike missions or air-to-air combat. Finally, if no Air Force tankers are present, organic tankers are required to accompany strike aircraft on missions beyond the maximum unrefueled combat radius of 600nm for F-35C. Each tanker is assumed to extend the radius of two strike fighters by 200nm. However, if Air Force tankers are present the need for organic tanking is eliminated. For this scenario, it is assumed that no Air Force tankers will be available. A graphical depiction of SGR vs. range can be seen in Figure 105.

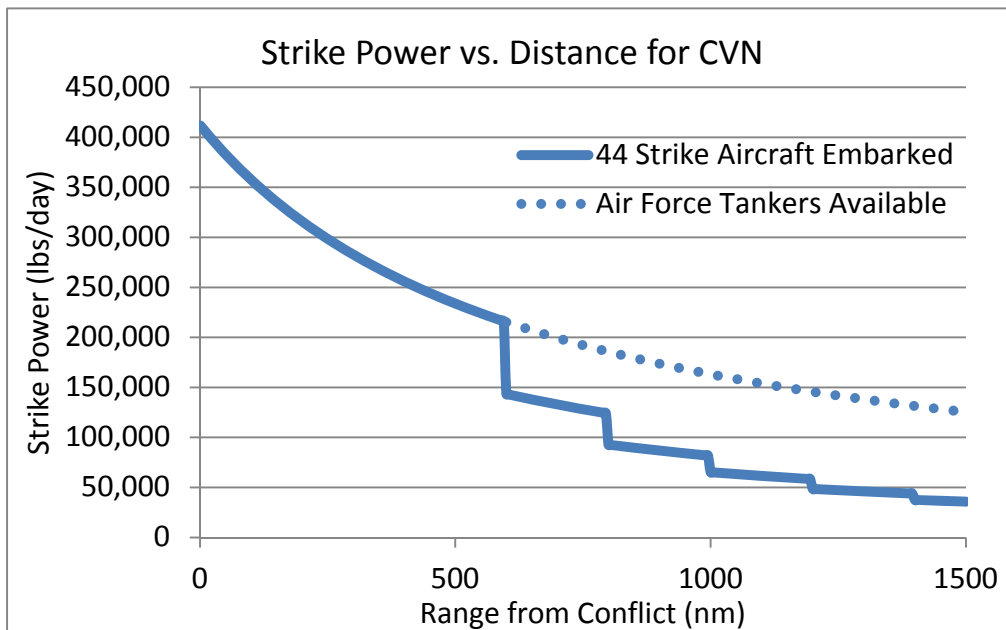


Figure 105. Strike power vs. distance for CVN.

CVN Strike Parameters	
Aircraft Type	F-35C
Assets	44
Fraction of Aircraft Mission Capable	0.75
Tankers for Recovery	6
Payload (lbs)	4000
Max Radius (nm)	600
Speed (kts)	500
Mission Success Rate	0.7

Table 21. CVN strike parameters.

b. CVL Strike Power

CVLs have a complement of 16 F-35Bs embarked (Weisser and Coles-Cieply 2009) for strike missions. This number of assets is reduced by 25% for aircraft that are not mission-capable. CVLs have no organic refueling capability. The combat radius of the F-35B is 450 nm and the payload is 2000 lbs. Due to the space and personnel limitations of the CVL, it is assumed that the SGR onboard a CVL can never exceed four sorties per day. The resultant strike effectiveness of a CVL can be seen below.

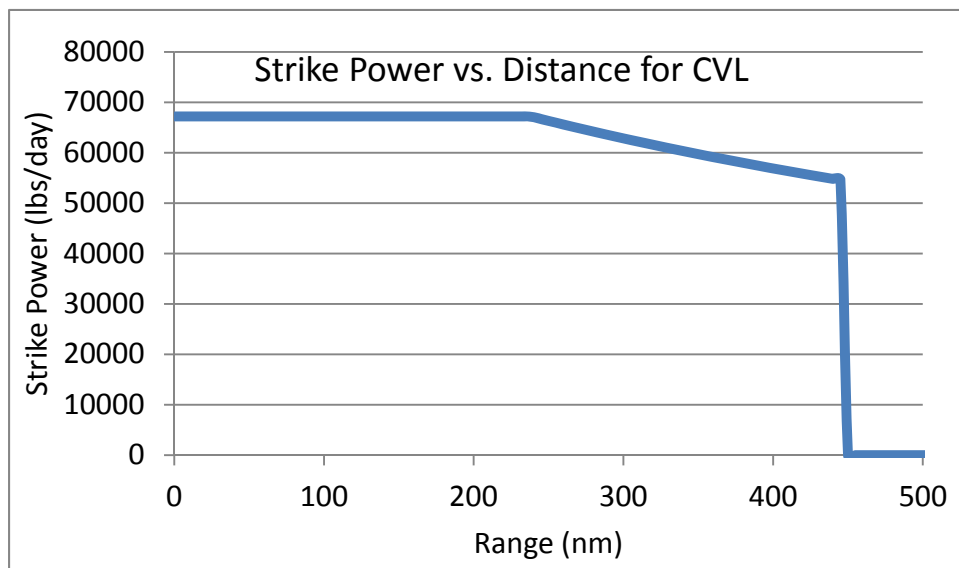


Figure 106. Strike power vs. distance for CVL

CVL Strike Parameters	
Aircraft Type	F-35B
Assets	16
Fraction of Aircraft Mission Capable	0.75
Tankers for Recovery	0
Payload (lbs)	2000
Max Radius (nm)	450
Speed (kts)	500
Mission Success Rate	0.7

Table 22. CVL strike parameters.

c. Sea Scout Strike Power

The upgraded Sea Scout possesses LRASM missiles for strike missions. They have a payload of 1,000lbs per missile and a maximum range of 230nm. At most, 56 missiles can be carried in vertical launch tubes. These missiles are one-way threats therefore the associated SGR is 1.0. For more details on the Sea Scout strike capabilities, please see the Sea Scout section of the report. The resultant strike effectiveness of a Sea Scout can be seen below in Figure 107.

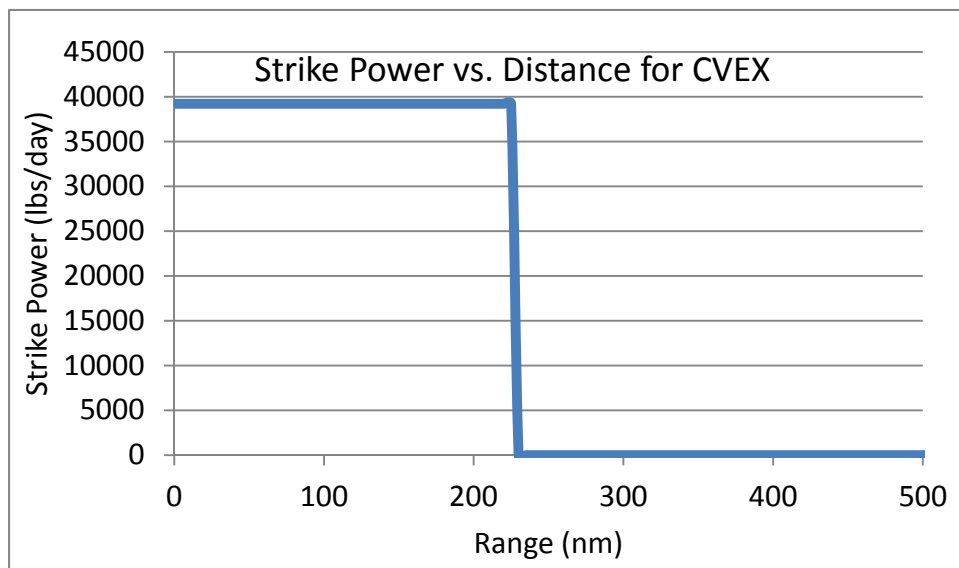


Figure 107. Strike power vs. distance for Sea Scout

Sea Scout Strike Parameters	
Aircraft Type	LRASM
Assets	56
Fraction of Aircraft Mission Capable	1
SGR	1
Payload (lbs)	1000
Max Radius (nm)	230
Mission Success Rate	0.7

Table 23. Sea Scout strike parameters

d. EAB Strike Power

EABs have a complement of six F-35Bs for strike missions. This number of assets is reduced by 25% for aircraft that are not mission capable. EABs have no aerial refueling capability. The combat radius of the F-35B is 450nm and the payload is 2000lbs. Due to the personnel and maintenance limitations of the EAB, it is assumed that the SGR at an EAB can never exceed four sorties per day. The resultant strike effectiveness of an EAB can be seen below in Figure 108.

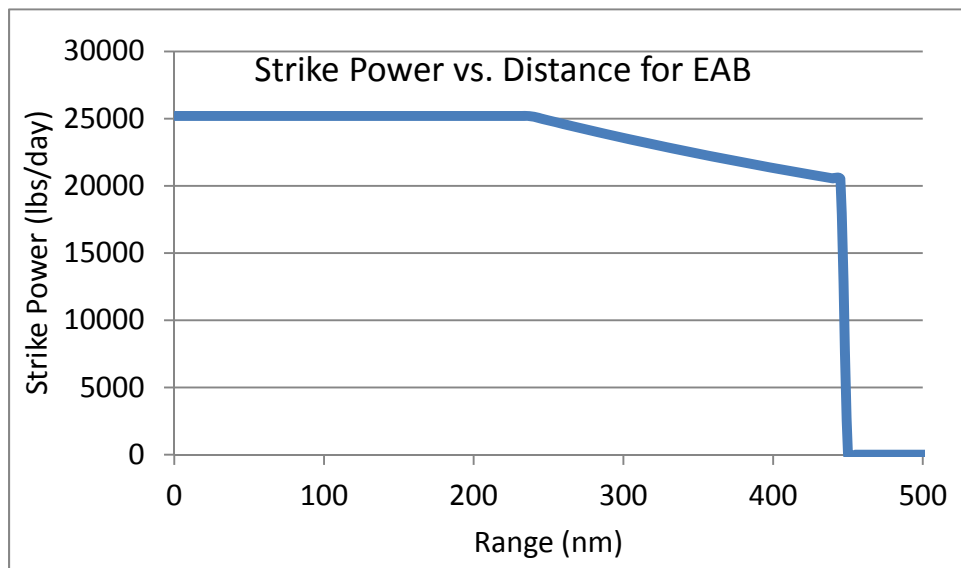


Figure 108. Strike power vs. distance for EABs

EAB Strike Parameters	
Aircraft Type	F-35B
Assets	6
Fraction of Aircraft Mission Capable	0.75
Tankers for Recovery	0
Payload (lbs)	2000
Max Radius (nm)	450
Speed (kts)	500
Mission Success Rate	0.7

Table 24. EAB strike parameters

5. Counter-Air Data Set Development

The next step of this analysis was to model counter-air effectiveness as a function of range from the conflict. The measure of counter-air effectiveness is:

$$\text{Counter Air Power} = \text{Assets} \times \text{RCP} \times \text{On Station Time} \times \text{Mission Success Rate} \times \text{SGR}$$

Assets are the number of mission-capable fighters available. RCP is relative combat power, which is a measure of the air-to-air ability of various aircraft types. For this analysis, RCP is base-lined to an F-18 aircraft, which is given an RCP value of 1.0. F-35 aircraft are estimated to be roughly twice as effective at air-to-air combat so they are assigned an RCP value of 2.0. On station time is the amount of effective counter-air time provided by each sortie. This time is limited by either fuel or by the number of air-to-air missiles carried. In a large scale air-to-air battle it is estimated that targets can be located and missiles fired at an average rate of 15 minutes per missile. Therefore, effective on-station time is capped by the number of missiles carried multiplied by 15 minutes per missile. Mission success rate and SGR remain the same as the previous sections.

A graph of each option's counter-air power vs. distance can be seen in Figure 109. Each of the specific options will be discussed in more detail in the following sections.

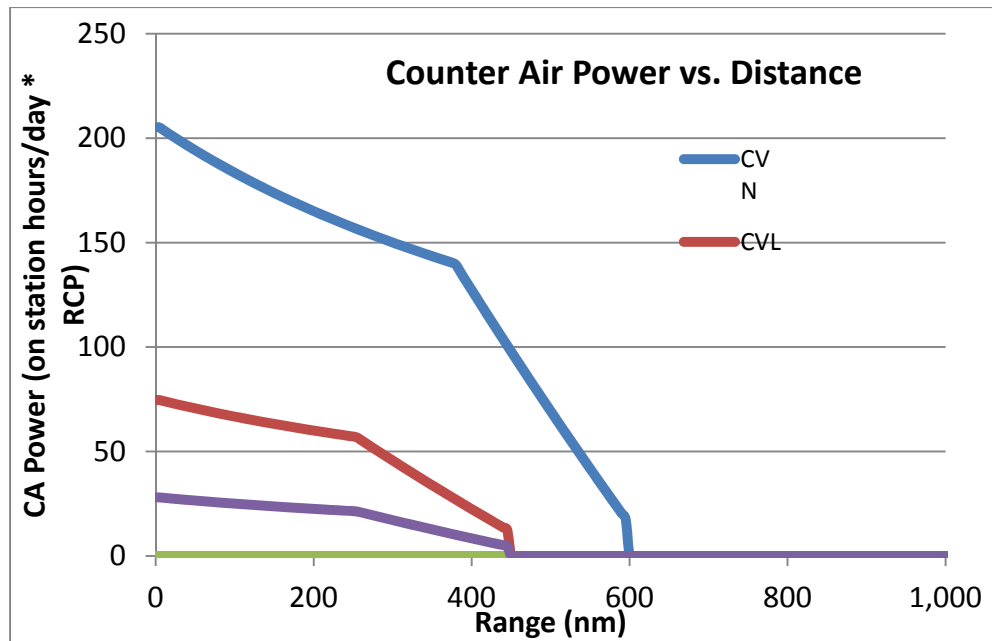


Figure 109. Strike power vs. distance for all options

a. CVN Counter-Air Power

The CVN counter-air assets are the same set of 44 strike aircraft used in the strike mission. They are reduced by 25% for aircraft that are not mission-capable. The RCP of the F-35C is 2.0. Its mission success rate is 70%. SGR is calculated the same way as for strike missions and it decreases with range. On-station time is calculated by subtracting flight time from total endurance. The endurance of an F-35C is 2.5 hours. Each F-35C can carry four air-to-air missiles (IHS Jane's 2013) so total on-station time for counter-air missions can never exceed one hour per aircraft. The profile of CVN counter-air power vs. range can be seen as the blue line in Figure 109.

CVN Counter Air Parameters	
Aircraft Type	F-35C
Assets	44
Fraction of Aircraft Mission Capable	0.75
Endurance (hours)	2.5
Max Radius (nm)	600
Speed (kts)	500
Air-to-air Missiles	4
RCP	2
Mission Success Rate	0.7

Table 25. CVN counter air parameters

b. CVL Counter-Air Power

The CVL's counter-air assets are 16 F-35Bs. They are reduced by 25% for aircraft that are not mission capable. The RCP of the F-35B is 2.0. Its mission success rate is 70%. SGR is calculated as previously described and it decreases with range. On station time is calculated by subtracting flight time from total endurance. The endurance of an F-35B is 2.0 hours. Each F-35B can carry 4 air-to-air missiles (IHS Jane's 2013) so total on station time for counter air missions can never exceed 1 hour per aircraft. The profile of CVL counter air power vs. range can be seen as the red line in Figure 109.

CVL Counter Air Parameters	
Aircraft Type	F-35B
Assets	16
Fraction of Aircraft Mission Capable	0.75
Endurance (hours)	2
Max Radius (nm)	450
Speed (kts)	500
Air-to-air Missiles	4
RCP	2
Mission Success Rate	0.7

Table 26. CVL counter air parameters

c. Sea Scout Counter-Air Power

Sea Scout is not equipped with any assets capable of counter-air mission. It is limited to strike and ISR only.

d. EAB Counter-Air Power

An EAB's counter-air assets are six F-35Bs. They are reduced by 25% for aircraft that are not mission capable. The RCP of the F-35B is 2.0. Its mission success rate is 70%. SGR is calculated as previously described and it decreases with range. On-station time is calculated by subtracting flight time from total endurance. The endurance of an F-35B is 2.0 hours. Each F-35B can carry four air-to-air missiles (IHS Jane's 2013) so total on-station time for counter-air missions can never exceed one hour per aircraft. The profile of EAB counter-air power vs. range can be seen as the purple line in Figure 109.

EAB Counter Air Parameters	
Aircraft Type	F-35B
Assets	6
Fraction of Aircraft Mission Capable	0.75
Endurance (hours)	2
Max Radius (nm)	450
Speed (kts)	500
Air-to-air Missiles	4
RCP	2
Mission Success Rate	0.7

Table 27. EAB counter air parameters

6. ISR Data Set Development

The next step of this analysis was to model ISR effectiveness as a function of range from the conflict. The measure of ISR effectiveness is:

$$ISR\ Power = Assets \times On\ Station\ Time \times Mission\ Success\ Rate \times SGR$$

Assets are the number of ISR capable aircraft. Mission success rate is the probability of an ISR mission being completed successfully. SGR is sortie generation

rate. It is a calculated as previously described. On-station time is calculated by subtracting the flight time from the total endurance. For several aircraft a maximum range is specified beyond which the aircraft cannot perform mission duties. The ISR range profiles for the four options can be seen in Figure 110.

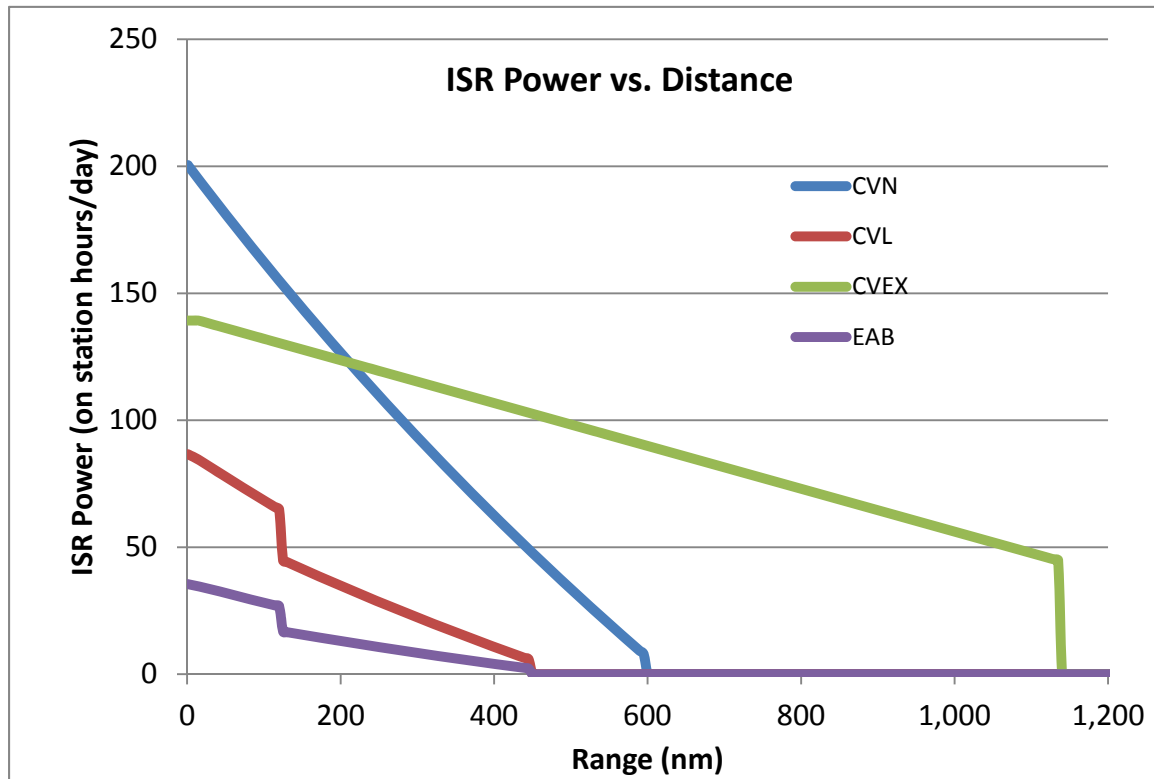


Figure 110. ISR power vs. distance for all options.

a. CVN ISR Power

Fighter aircraft perform the CVN's ISR mission. E-2D early warning aircraft provide communications and command and control for the fighters. The fighters can perform both ISR and strike missions simultaneously. Therefore, the assets available for ISR are 44 fighters reduced by 25% for aircraft that are not mission-capable. The mission success rate is 70%. SGR is calculated as previously described and it decreases with range. On-station time is calculated by subtracting flight time from total endurance. The endurance of an F-35C is 2.5 hours. The profile of CVN ISR power vs. range can be seen as the blue line in Figure 110.

CVN ISR Parameters	
Aircraft Type	F-35C
Assets	44
Fraction of Aircraft Mission Capable	0.75
Endurance (hours)	2.5
Max Radius (nm)	600
Speed (kts)	500
Mission Success Rate	0.7

Table 28. CVN ISR parameters.

b. CVL ISR Power

The CVL is equipped with both fighters and MQ-8 Fire Scout helicopters that can perform ISR missions. The total ISR provided is a combination of both of these assets. The fighter assets available are 16 F-35Bs reduced by 25% for aircraft that are not mission-capable. There are four MQ-8 Fire Scouts onboard a CVL (Weisser and Coles-Cieply 2009). The mission success rate for both types is 70%. SGR is calculated as previously described and it decreases with range. On -station time is calculated by subtracting flight time from total endurance. The endurance of an F-35B is 2.0 hours and a MQ-8 is 10 hours. The profile of CVL ISR power vs. range can be seen as the red line in Figure 110.

CVL ISR Parameters		
	MQ-8 Fire Scout	F-35B
Aircraft Type		
Assets	4	16
Fraction of Aircraft Mission Capable	0.75	0.75
Endurance (hours)	10	2
Max Radius (nm)	110	450
Speed (kts)	110	500
Mission Success Rate	0.7	0.7

Table 29. CVL ISR parameters.

c. Sea Scout ISR Power

The Sea Scout is equipped with 21 dedicated Boeing Hummingbird ISR UAV platforms. These UAVs are capable of flying for 20 hours at a speed of 165kts. They have a maximum range of 1125nm. For more specific details about the capabilities of Sea Scout UAVs please see the section discussing Sea Scout. The mission success rate is 70%. SGR is calculated as previously described and it decreases with range. On-station time is calculated by subtracting flight time from total endurance. The profile of EAB ISR power vs. range can be seen as the green line in Figure 110.

Sea Scout ISR Parameters	
Aircraft Type	UAV
Assets	21
Fraction of Aircraft Mission Capable	0.75
Endurance (hours)	20
Max Radius (nm)	1125
Speed (kts)	165
Mission Success Rate	0.7

Table 30. Sea Scout ISR parameters.

d. EAB ISR Power

The EAB is equipped with both fighters and Fire Scout helicopters that can perform ISR missions. The total ISR provided is a combination of both of these assets. The fighter assets available are six F-35Bs reduced by 25% for aircraft that are not mission-capable. There are two MQ-8 Fire Scouts as well. The mission success rate for both types is 70%. SGR is calculated as previously described and it decreases with range. On-station time is calculated by subtracting flight time from total endurance. The endurance of an F-35B is 2.0 hours and a MQ-8 is 10 hours. The profile of EAB ISR power vs. range can be seen as the purple line in Figure 110.

EAB ISR Parameters		
Aircraft Type	MQ-8 Firescout	F-35B
Assets	2	6
Fraction of Aircraft Mission Capable	0.75	0.75
Endurance (hours)	10	2
Max Radius (nm)	110	450
Speed (kts)	110	500
Mission Success Rate	0.7	0.7

Table 31. EAB ISR parameters.

7. Scenario Requirements

Next the team developed the specific mission requirements for the scenario. The scenario envisions the Spratly Islands as the center of the conflict. U.S. forces are positioning to help allied nations defend their claims over the disputed regions. A PLA fleet is heading south from the coast of China to reinforce red troops on in the Spratly Islands and to attack any U.S. ships encountered. In order to achieve victory, the U.S. force structure must be able to wage a major strike campaign around the Spratly Islands. This campaign is estimated to require at least 200,000lbs. of ordnance per day in the Spratly trapezoid depicted in Figure 111. This region will also require 48hrs per day of ISR, which equates to two aircraft on-station at all times. Finally, a minimal amount of counter-air presence (8 hours on-station per day) will be required.

In order to enable the strike campaign in the Spratly Islands, a barrier would be established between Vietnam and the Philippines to intercept any incoming bombers or fighter aircraft. This is where the major air battle is expected to take place. The barrier must be placed far enough away from the main fleet to allow interception of the hostile aircraft prior to launching anti-ship cruise missiles. This barrier can be seen in Figure 111. It consists of an ISR requirement of 96 hours per day, a strike requirement of 50,000lbs ordnance per day, and a counter-air requirement of 96 hours per day to fulfill four 24-hour combat air patrols.

The area of the Paracel Islands also could hold a significant number of targets in this scenario. This area requires 12 hours of ISR, 50,000lbs of ordnance, and 48 hours of

counter-air missions per day. The Paracel Islands lie outside the barrier of air protection, therefore most strike missions will be accompanied by sufficient counter-air equipped aircraft.

Finally, the Taiwan straits are a significant choke-point for surface vessels. Therefore, a persistent ISR capability accompanied by minor strike ability would be needed by U.S. forces.

These mission requirements are depicted in Figure 111.

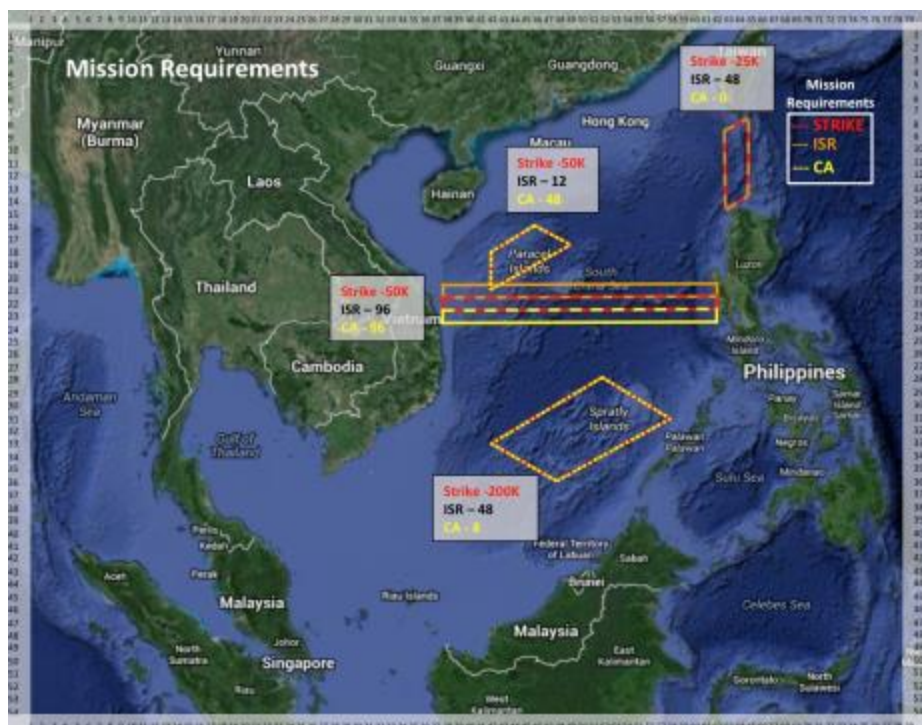


Figure 111. Baseline mission requirements.

Due to the inherent unpredictability adversary technology, the team decided to test the robustness of the alternatives by subjecting them to more rigorous requirements in addition to the baseline requirements. If, for example, the PLA fighters developed were twice as effective as anticipated the counter-air requirements for U.S. forces could double. Similarly, if PLA military targets had advanced hardening capabilities, it may take roughly twice as many strike missions to neutralize the same number of targets. Therefore, the mission requirements described previously were doubled. These mission

sets were tested individually and together to determine their impact on results. The doubled requirements can be seen in Figure 112.



Figure 112. Doubled mission requirements.

8. Results

The team sought to compare alternative force structures by limiting the types of platforms available in each optimization. The first case, and baseline for analysis, is a force structure composed of CVNs only. This equates to the current U.S. fleet where CVNs are the only current method of projecting naval air power. Next, CVNs are teamed with the Sea Scout to see how risk can be reduced by the addition of a dedicated UAV carrier. Then expeditionary air bases alone are used to meet the mission requirements. Next, EABs and Sea Scouts are paired together. Finally, CVNs, EABs, and Sea Scouts are all allowed into the solutions.

The results of these trials for the baseline set of mission requirements can be seen in Table 32.

Alternatives	Scenario Requirements: Optimal Solutions					
	Quantity			Cost (\$B)	Scaled Risk	Normalized Risk
	CVNs	EABs	Sea Scouts			
CVNs Only	2			21.9	3846	100%
CVN + Sea Scouts	1		1	11.6	1480	38%
EABs Only		22		31.0	1488	39%
EABs + Sea Scouts		10	3	16.0	724	19%
CVN + EAB + Sea Scouts	1	10	1	25.7	675	18%

Table 32. Optimal solutions for baseline mission requirements.

Preliminary testing showed that CVLs were not efficient solutions for this model and were excluded from further analysis. This was mainly due to two assumptions made in the process. First, CVLs were assumed to suffer the same risks at the same rates as CVNs. Second, CVL cost estimation was performed using the America class LHA as the analogous platform. If dedicated CVLs could be built cheaper or if its size was small enough to eliminate the threat of ballistic missiles, then CVLs may become a viable alternative. The team highly recommends this topic as a candidate for future study.

The results in Table 32. can also be plotted in a risk vs. cost graph. This shows that the solutions are stable over a wide range of costs. This can be seen in Figure 113. The red X's show the acquisition costs and risk of the optimal force structures that compose the horizontal lines.

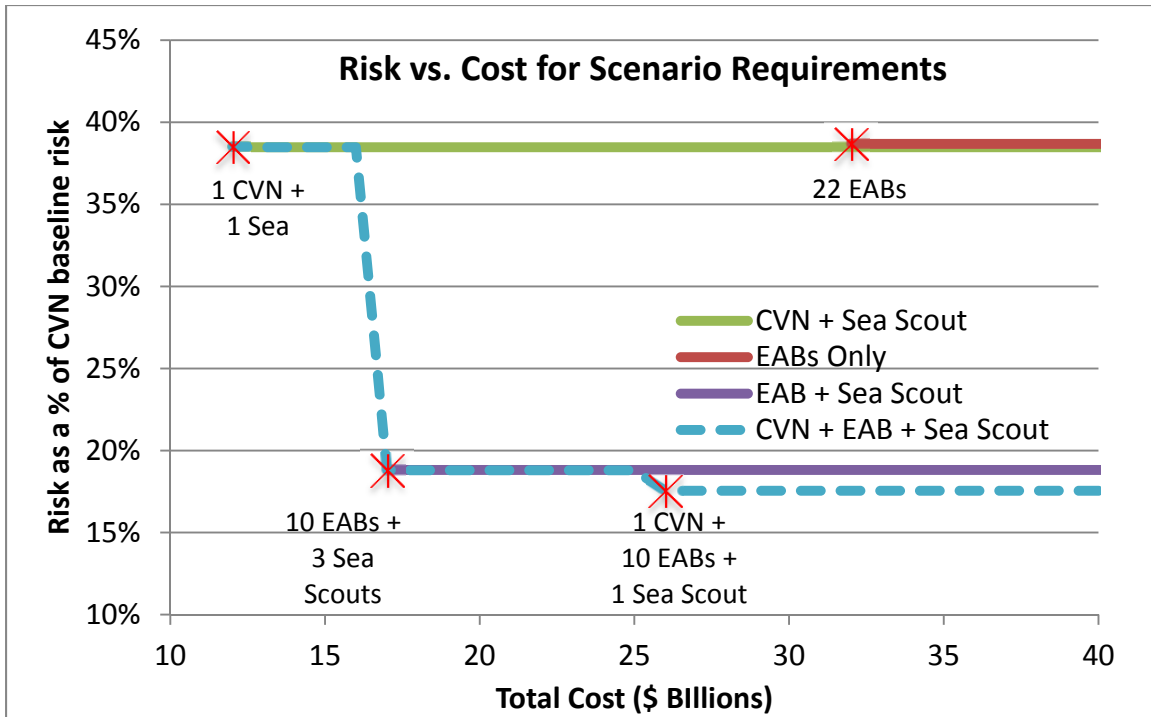


Figure 113. Risk vs. cost for baseline mission requirements.

This graph shows how the optimal solution changes with cost. The dashed blue line depicts the solutions when CVNs, EABs and Sea Scouts are all viable alternatives. The problem is infeasible when less than \$12 billion is available. At \$12 billion one CVN and one Sea Scout can meet the mission requirements. This incurs a risk of 38% of the baseline risk incurred by two CVNs operating alone. This is a significant drop in risk, which also comes with a much lower cost.

Please note that the risk incurred is a function of asset placement as well as force structure. The optimal placement of two CVNs to meet the mission requirements can be seen in Figure 114. and the optimal placement of one CVN and one Sea Scout can be seen in Figure 115.

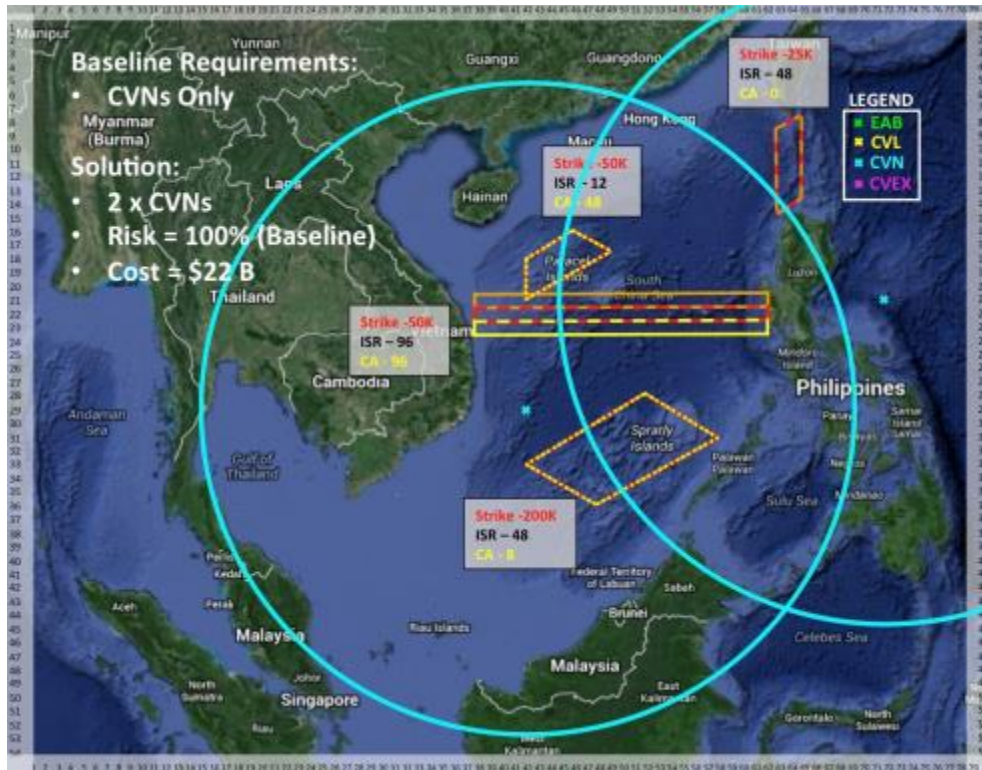


Figure 114. Optimal solution for CVNs only.

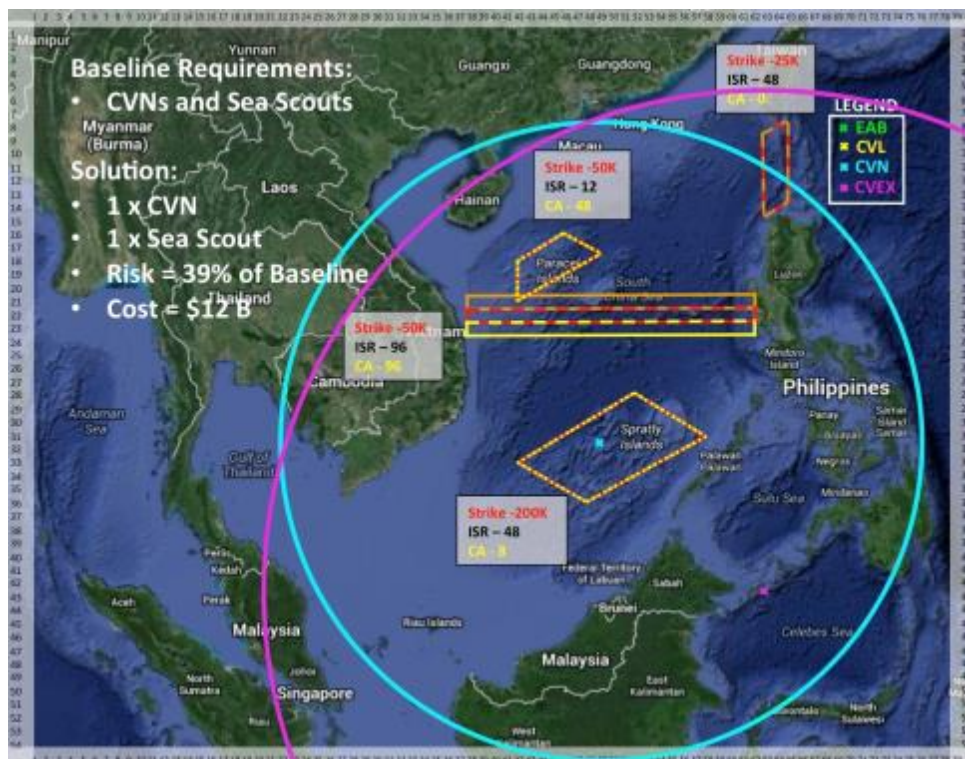


Figure 115. Optimal solution for CVNs and Sea Scouts.

The solution of one CVN and one Sea Scout remains the best solution for all costs less than \$17 billion. At \$17 billion a new optimal solution emerges consisting of ten EABs and three Sea Scouts. This incurs 19% of the risk of two CVNs. This provides an even lower risk in exchange for a larger price tag. The placement of assets in this solution can be seen in Figure 116.

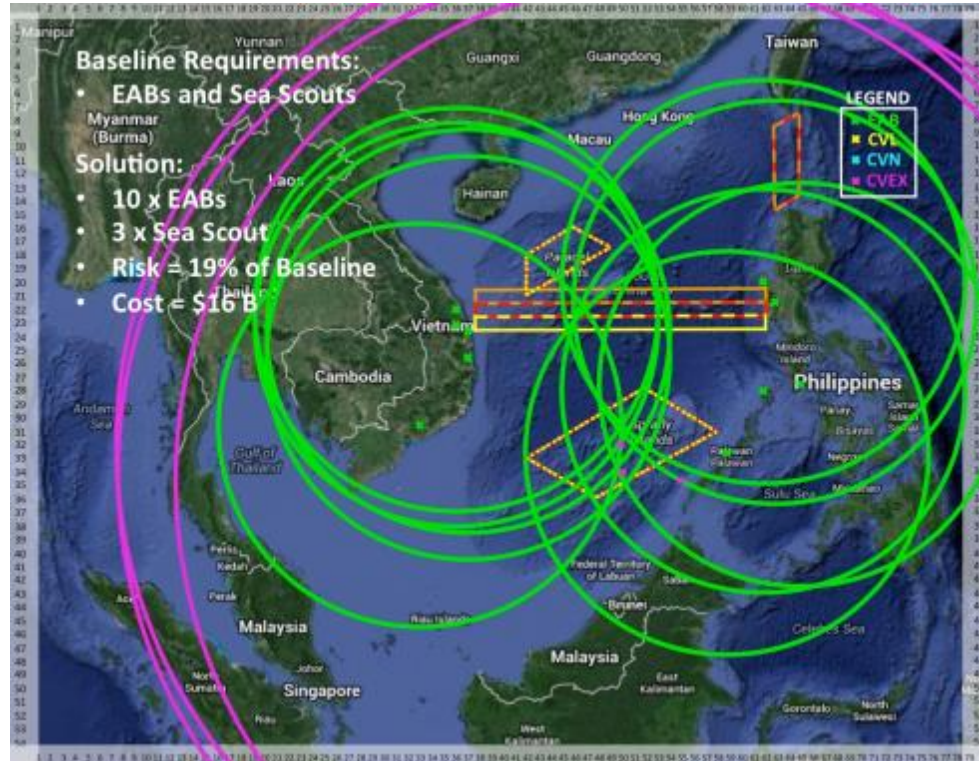


Figure 116. Optimal solution for EABs and Sea Scouts.

This solution of ten EABs and three Sea Scouts dominates the alternative of EABs only. Using EABs alone requires 22 bases and suffers a risk of 39% of the baseline value. However, EABs alone still offer a risk reduction from the baseline case of two CVNs although at a higher cost. The optimal placement of EABs can be seen in Figure 117. The optimal placement relies heavily on both Vietnam and the Philippines to reach both sides of the requirements barrier.



Figure 117. Optimal solution for EABs only

Finally, if \$26 billion or greater is available for force structure acquisition, the optimal solution consists of one CVN, ten EABs, and one Sea Scout. This alternative has the lowest risk at 18% of the baseline. This optimal placement of this force structure can be seen in Figure 118.



Figure 118. Optimal solution for CVNs, EABs and Sea Scouts

The optimal solutions for the various combinations were plotted on a cost vs. risk chart to determine the efficient solutions. An efficient solution offers the most risk reduction for a given dollar amount. This plot can be seen in Figure 119. Increasing risk is down on the vertical axis and increasing cost is right on the horizontal axis. Therefore, the best force structures are those closest to the top left corner of the graph.

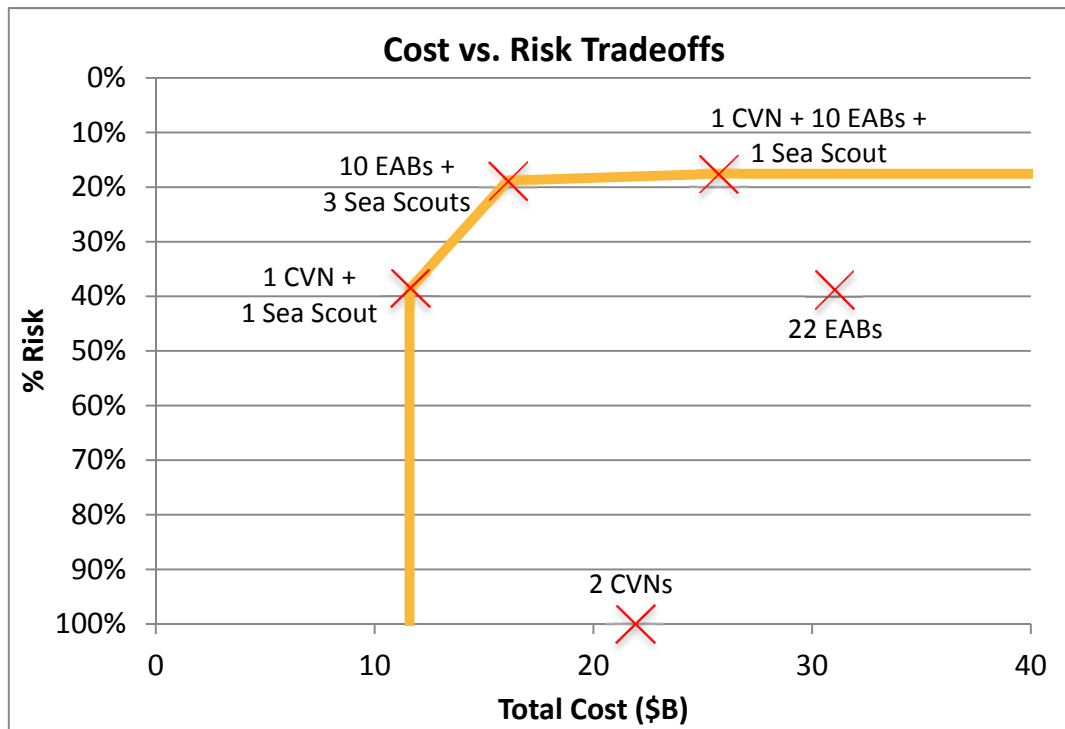


Figure 119. Cost vs. risk efficiency of alternatives

There are three efficient solutions for examination. One CVN and one Sea Scout offer the least expensive alternative to achieve a significant reduction in risk. Then for approximately \$5 billion more, ten EABs and three Sea Scouts offer an even greater reduction in risk. Finally, for an additional \$10 billion only a minor further reduction in risk can be achieved. Therefore, the first two alternatives offer the greatest return on investment. The force structure with only CVNs and the force structure with only EABs are not efficient solutions because a greater reduction in risk can be achieved for a lesser total cost.

All of the efficient solutions contain Sea Scout in the force structure. Therefore, it can be concluded that Sea Scout would in fact help to achieve the goals of reducing risk and cost when operating in an A2AD environment.

9. Sensitivity Analysis

Next several different cases were examined to see how the solution changes when some of the key inputs are varied. First the team explored the possibility that it underestimated the scale of the mission requirements. For this case, each of the mission requirements was doubled and the optimization was performed on them individually and then all together. This protects against a situation in which PLA capabilities advance faster than anticipated and thus the U.S. commander in the conflict needs more capability.

The first trial tested was one with doubled ISR requirements. This situation could arise if PLA counter detection capabilities advance more rapidly than anticipated. This could require twice as many aircraft on-station to find and identify targets of interest. The results from doubled ISR requirements can be seen in Table 33. and Figure 120.

Alternatives	Double ISR Requirements: Optimal Solutions					
	Quantity			Cost (\$B)	Scaled Risk	Normalized Risk
	CVNs	EABs	Sea Scouts			
CVNs Only	3			32.9	5680	148%
CVN + Sea Scouts	1		1	11.6	2574	67%
	1		1	12.3	1495	39%
EABs Only		48		67.7	3290	86%
EABs + Sea Scouts		10	3	16.0	724	19%
CVN + EAB + Sea Scouts	1	10	1	25.7	687	18%

Table 33. Double ISR requirements, optimal solutions

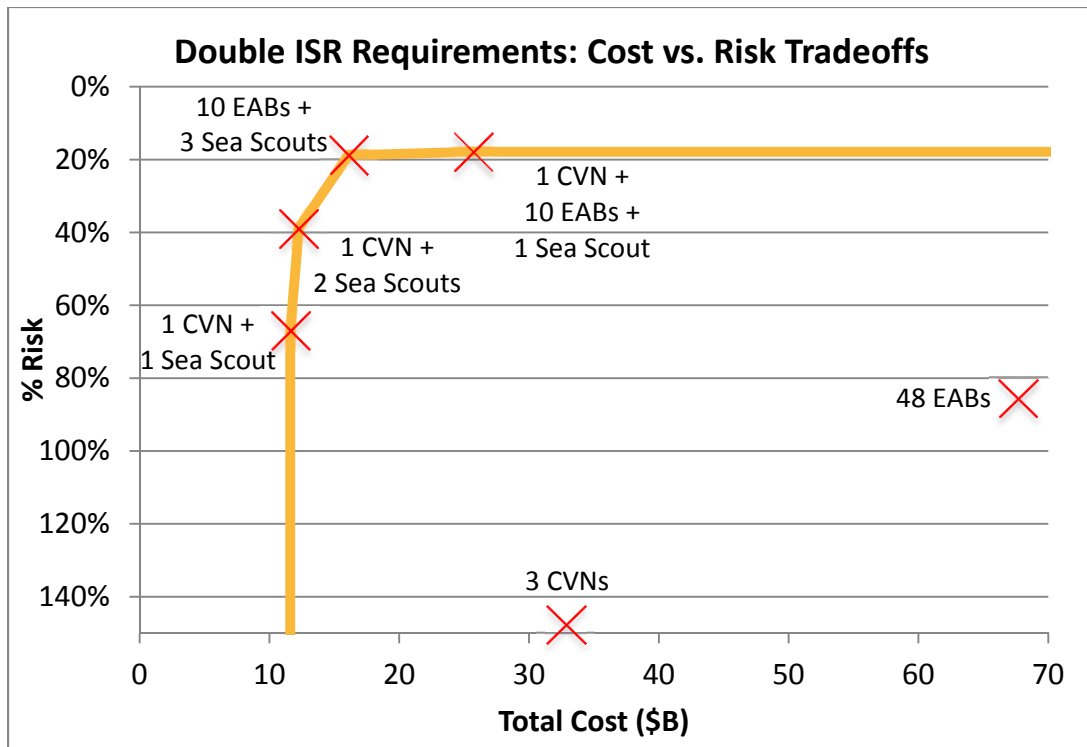


Figure 120. Double ISR requirements, cost vs. risk.

This shows that ISR is extremely demanding in the absence of Sea Scout. When only CVNs are involved, three are required instead of the original two. When only EABs are used, 48 are required instead of the original 22. However, when Sea Scout is added to the force structure the solutions are generally unchanged. This shows that Sea Scout has additional excess ISR capability and is by far the best choice to meet the ISR requirements.

The next case studied was doubled counter-air requirements. This case could arise if PLA aircraft are more effective or more numerous in 2025 than anticipated. This would result in twice as many air-to-air equipped U.S. fighter required to achieve victory. The results from this trial can be seen in Table 34. and Figure 121.

Double CA Requirements: Optimal Solutions						
Alternatives	Quantity			Cost (\$B)	Scaled Risk	Normalized Risk
	CVNs	EABs	Sea Scouts			
CVNs Only	2			21.9	4018	104%
CVN + Sea Scouts	2		1	22.6	2909	76%
EABs Only		23		32.4	1545	40%
EABs + Sea Scouts		18	3	27.4	1298	34%
CVN + EAB + Sea Scouts	1	4	1	17.3	2629	68%
	1	5	1	18.7	1848	48%
	1	18	1	37.0	1263	33%

Table 34. Double counter air requirements, optimal solutions.

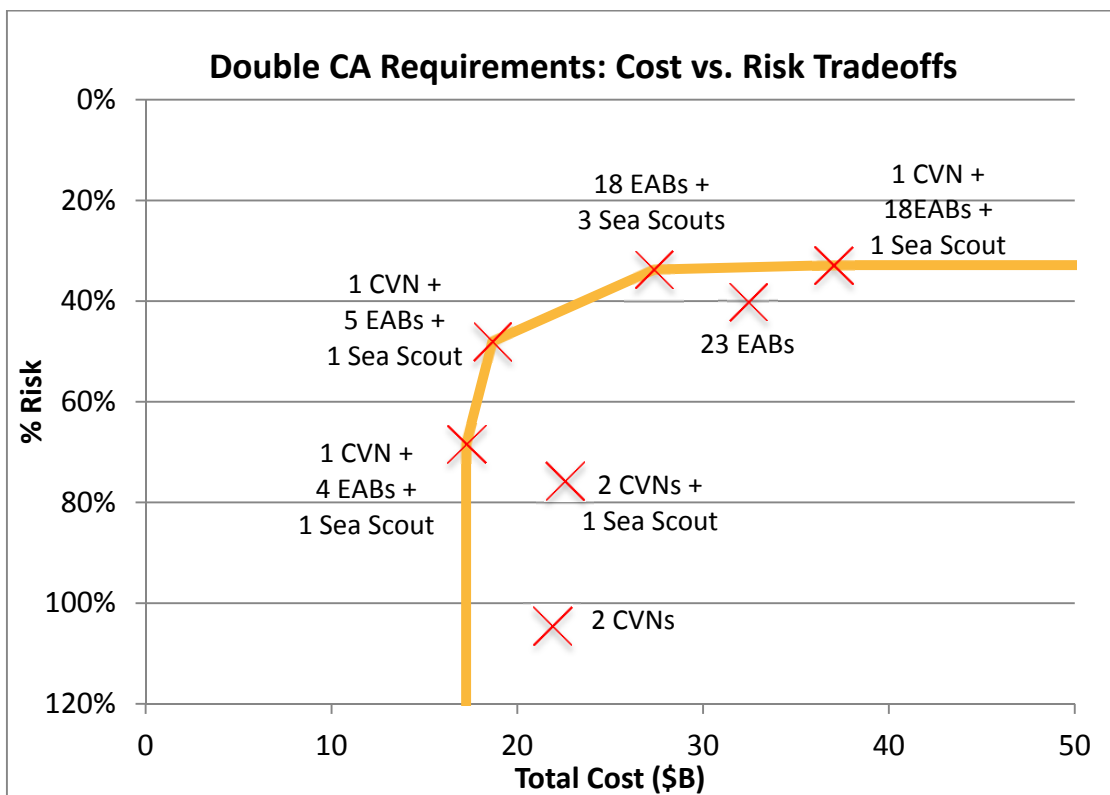


Figure 121. Double counter-air requirements, cost vs. risk.

Doubled counter-air requirements prove to be one of the most stressful situations for the U.S. forces. One CVN cannot meet the requirements on its own and either EABs or an additional CVN is required to fill the gap. EABs are the better choice in this

situation because they are scalable and the number utilized can be expanded or reduced to meet the requirements. In contrast, if an entire additional CVN is brought into the conflict then the entire air wing is exposed to more risk.

The next case studied was doubled strike requirements. This case could arise if PLA targets utilized hardened structures or counter-targeting abilities that made each strike less effective. Twice the amount of ordnance would be needed to destroy the same number of targets. The results for doubled strike requirements can be seen in Table 35. and Figure 122.

Double Strike Requirements: Optimal Solutions						
Alternatives	Quantity			Cost (\$B)	Scaled Risk	Normalized Risk
	CVNs	EABs	Sea Scouts			
CVNs Only	2			21.9	3846	100%
CVN + Sea Scouts	2		1	22.6	1480	38%
	1		3	12.9	1522	40%
EABs Only		30		42.3	1545	40%
EABs + Sea Scouts		10	13	27.4	1298	34%
CVN + EAB + Sea Scouts	3	10	1	47.6	682	18%
	2	10	3	38.0	721	19%
	1	10	7	29.7	782	20%

Table 35. Double strike requirements, optimal solutions.

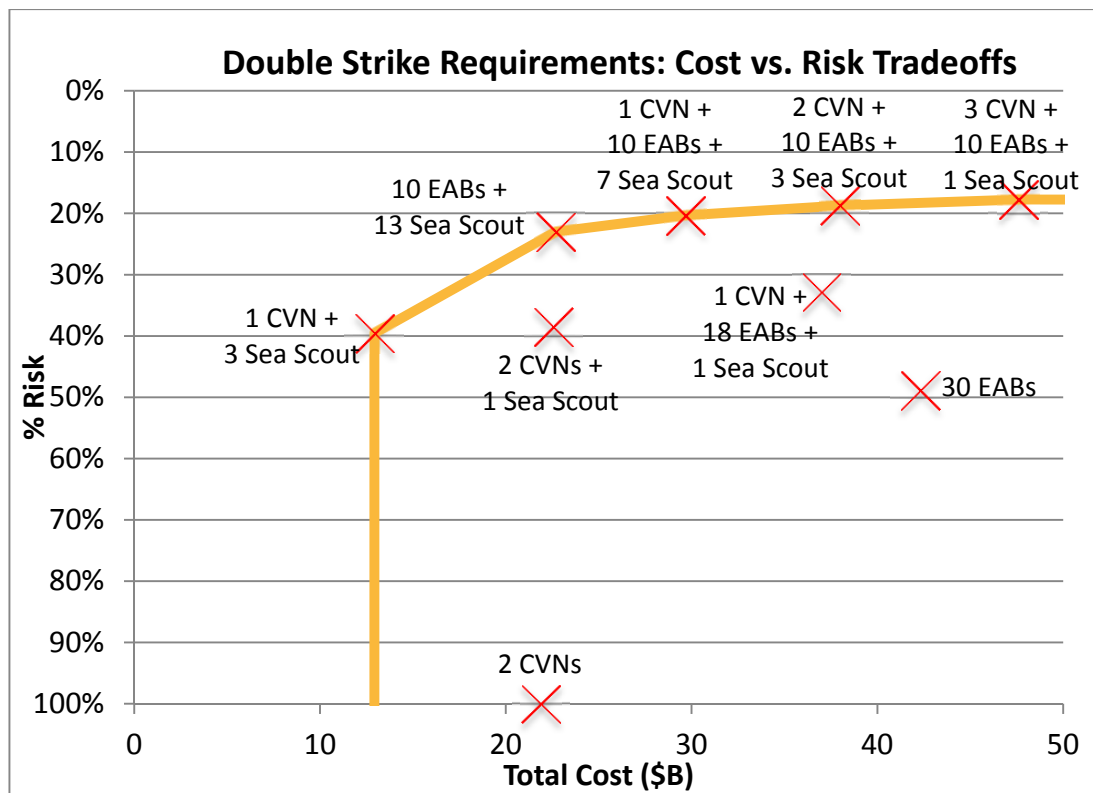


Figure 122. Double strike requirements, cost vs. risk.

These solutions are similar to the baseline solutions, but they utilize additional Sea Scouts to make up for the strike shortfalls. The complement of 56 LRASM missiles makes the Sea Scout an effective strike platform as well as an effective ISR platform. CVNs are still the most cost efficient, long-range strike platforms and given unlimited funds three CVNs placed far away from the threats could still mount a formidable strike campaign. However, this requires Sea Scouts and EABs to relieve the ISR and counter-air requirements deep within the A2AD threat environment.

Finally, if all mission requirements are doubled at the same time, representing the most challenging of scenarios studied thus far, the results can be seen in Table 36. and Figure 123.

Double All Requirements: Optimal Solutions						
Alternatives	Quantity			Cost (\$B)	Scaled Risk	Normalized Risk
	CVNs	EABs	Sea Scouts			
CVNs Only	3			32.9	5680	148%
CVN + Sea Scouts	2		2	23.2	2922	76%
	2		1	22.6	3893	101%
EABs Only		51		71.9	3431	89%
EABs + Sea Scouts		18	9	31.3	1401	36%
CVN + EAB + Sea Scouts	3	18	1	58.9	1270	33%
	2	18	3	49.3	1285	33%
	2	5	1	29.6	1858	48%
	1	5	2	19.3	1867	49%
	1	4	2	17.9	2654	69%

Table 36. Double all requirements, optimal solutions.

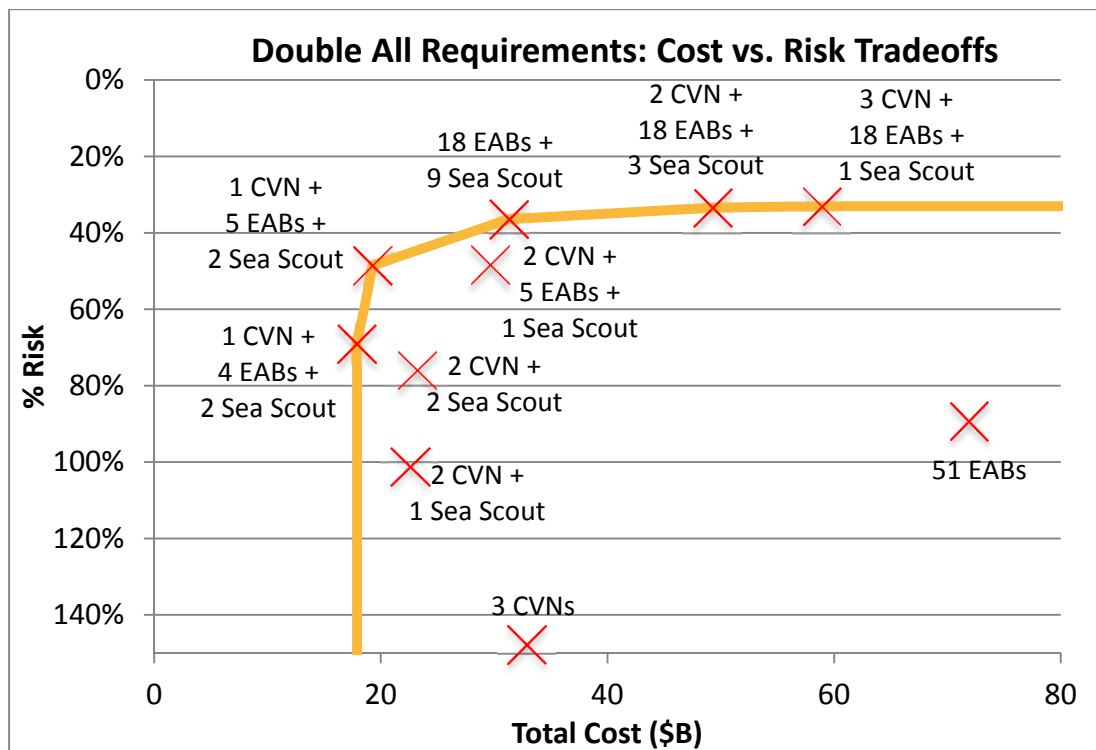


Figure 123. Double all requirements, cost vs. risk.

When all requirements are doubled, the best solutions consist of all three force structure alternatives. There are numerous solutions along the efficient frontier, but the

one that has the most risk reduction for the best price is one CVN with five EABs and two Sea Scouts. This provides a robust solution that can handle a doubling of any of the original requirements for a cost of \$19 billion. This force structure reduces the risk to 49% of the baseline risk.

Finally, for this analysis the Sea Scout was equipped with Hummingbird UAVs with excellent range and endurance specifications. However, if the U.S. Navy was unable to acquire UAVs with these specifications this could impact the effectiveness of the Sea Scout. Therefore, the group performed a sensitivity analysis to compare the optimal solutions for Sea Scout with both Hummingbird UAVs and less capable UAVs that meet the minimum required specifications described in the Sea Scout portion of the report. The comparison of capabilities can be seen in Table 37. and the results of this analysis can be seen in Figure 124.

Sea Scout ISR UAV Compliment		
Aircraft Type	Hummingbird UAV	Minimum Requirements
Number of Assets	21	12
Endurance (hours)	20	6
Max Radius (nm)	1125	200
Speed (kts)	165	135

Table 37. Hummingbird UAV parameters vs. minimum requirements.

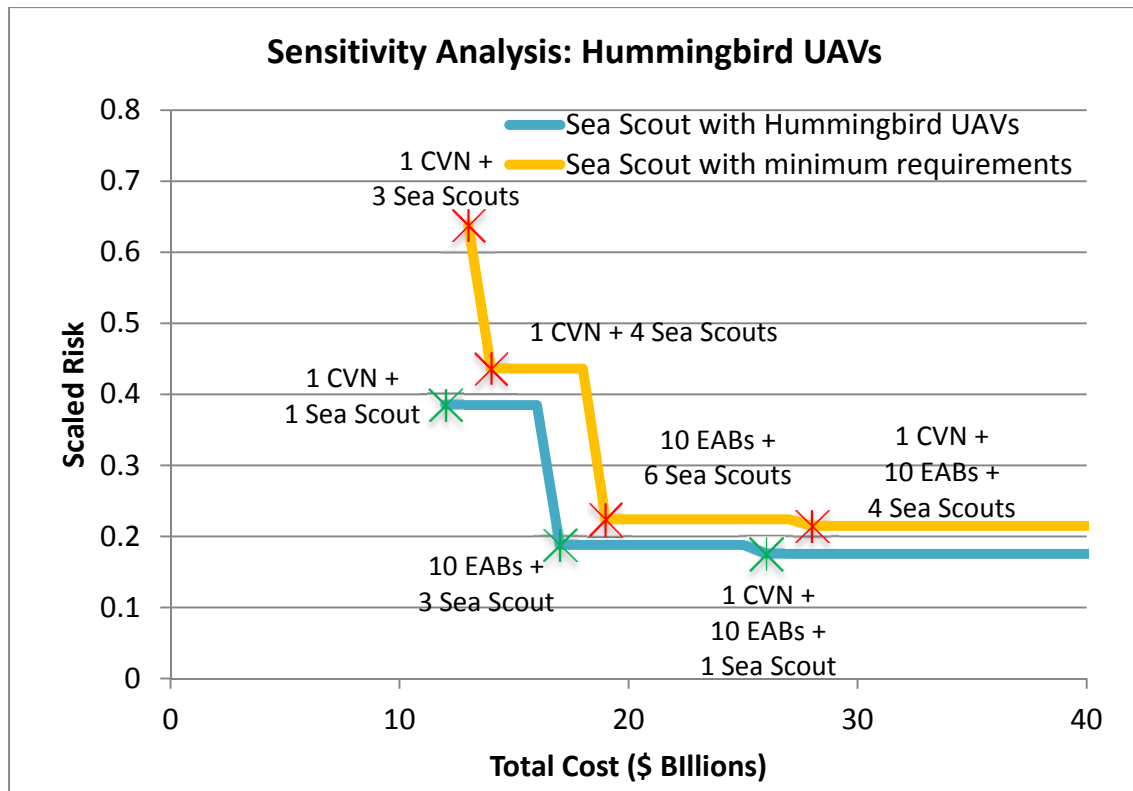


Figure 124. Sensitivity analysis of Hummingbird UAVs.

The results show that the optimal solutions are somewhat insensitive to the specific ISR capabilities of the Sea Scout UAVs. All of the solutions have similar force compositions with the exception that an additional three Sea Scouts are required to perform the duties of one original Sea Scout with Hummingbird UAVs. This shows that the team's conclusion is still valid that the U.S. Navy should pursue an unmanned ISR platform to augment the current fleet capabilities. The ISR requirements can be reduced by a few extremely capable UAVs or with a larger number of moderately capable UAVs.

10. Computation

These formulations were solved using General Algebraic Modeling System (GAMS) software with CPLEX version 12.3.0.0. Typical runs utilize 16,316 constraints and 6,222 binary variables. Typical run time for the ILP to minimize cost is less than one minute on a Dell Precision T7500 computer with two Intel Xeon 3 GHz CPUs and 96 GB RAM. Typical run time for the ILP to minimize risk is between 5 and 50 minutes on the same computer.

Most trials were solved to 100% optimality. However, rare cases when total budget values were slightly less than the total cost for an optimal force structure resulted in extremely long run times with large gaps in optimality. For example, one trial for the doubled strike requirements with \$37B in allowable budget was interrupted at 29% from optimality after 96 hours of run time. However, these rare instances do not adversely affect the conclusions drawn from this model. The force structures that compose the steps of the cost vs. risk function are stable over large ranges of cost and their compositions can be determined at other points on the curve. In the example described previously, the ILP solved quickly for a \$36B and \$38B budget. Therefore, it is not important what happens precisely at \$37B, but rather the composition of the force structure to which it is transitioning.

11. Conclusion

All of the optimal solutions discussed above are compiled in Figure 125. The baseline mission solutions are depicted as the yellow line and the more stringent requirements are the other colors.

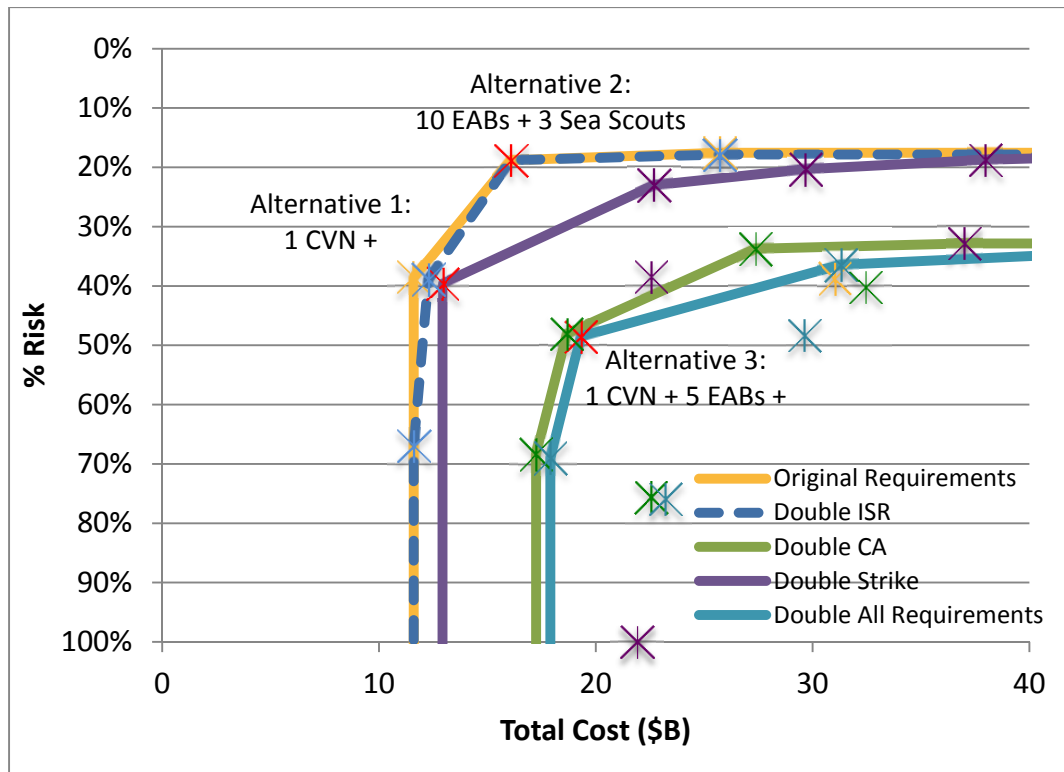


Figure 125. Cost vs. risk for all optimal solutions.

Three force structure alternatives are depicted in red that meet increasingly difficult requirements while at the same time reducing risk substantially from the baseline case of two CVNs operating alone. Of the three solutions shown, Alternative 2 reduces risk the most, to 19% of the baseline risk. It meets both the original requirement set and the doubled ISR requirement set. However, if the strike requirement was also doubled, then Alternative 1 provides the best value and reduces risk to 40% of baseline. Finally, if all requirements were doubled including counter-air, then Alternative 3 could still meet this challenge and reduce risk significantly while doing so.

It can also be seen from the curves that a doubled counter-air requirement is the most difficult to satisfy. These optimal force structures require the largest budgets and reduce risk the least from the baseline case. Therefore, a system that can achieve a greater counter-air capability for less risk is a highly desirable asset. The MTX can fill this gap. When operated from CVNs or EABs the MTX can provide longer on-station time and greater ranges in the counter-air domain. Although, due to time constraints, the Team was

unable to test the impact of MTX in this analysis, it is likely that the increased counter-air capabilities can decrease the overall risk to the fleet even further.

In order to compose any of these force structures, the Navy must commit to fielding an unmanned ISR platform to reduce the mission demands on a carrier. This ISR UAV embarked on a platform such as Sea Scout could significantly reduce the risk to the Fleet in an A2AD environment. Additionally, dispersed basing options such as EABs provide another way to reduce risk without the acquisition of new platforms. However, the Navy must invest in the training and personnel necessary so that they can build these bases quickly and efficiently when they are needed.

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XI. COMBAT ATTRITION - MANA SIMULATION AND LANCHESTER ANALYSIS

A. SIMULATION SOFTWARE: MANA

MANA, or Map Aware Non-uniform Automata, is an agent-based, time-stepped, stochastic, mission-level model. MANA was developed by the New Zealand Defense Technology Agency with the goal to create an abstraction of a scenario that captures the essence of the physical and behavioral aspects (SEED Center for Data Farming 2013).

B. MODELING IN MANA

MANA allows the scenario to be depicted through placement and representation of entity groups. An entity group or “squad” as it is known in MANA is a representation of real-world physical assets in simulation with some type of behavioral pattern. The control of the entity group is through parameters such as the personality of the entities within the group, its waypoints, sensor range, communication range, and probability of hit for its weapons. Personality of the entity groups are set by the influence of information that entities within the groups pick-up from their environment, such as the presence of different enemy entity types, presence of own-force entities, information about enemy and friendly forces obtained through information data exchange from other exchanges, and its own waypoints. The personality of weapons and sensor parameters may be set differently based on a set of built-in detection criteria. For example, when an enemy entity is detected, MANA will transition the entity to “Enemy Contact” state and the personality for that weapon/sensor entity is set to be biased towards targeting/tracking the enemy entity.

C. MANA MODEL GOALS

Specific scenarios of the Distributed Air Wing system-of-systems CONOP were modeled in MANA and compared to the traditional CVN CONOP to explore the different Force-Exchange Ratios that would result. This model specifically tested the defensive counter-air ability of the DAW to react against enemy aircraft attacks.

D. MODEL SETUP AND ASSUMPTIONS

The experiment was divided into two scenarios to determine the effectiveness of each CONOP in terms of Force-Exchange Ratio. The model used the alternatives generated by the force structure optimization model as the baseline for the experimentation.

E. ALTERNATIVES TO BE TESTED:

The three alternatives generated were as followed:

1. Alternative 1: Blue CVN Southeast of Palawan

20 Blue fighter aircraft are carried by the Blue CVN operating southeast of the Palawan Island and are launched at 30 second intervals to counter the Red forces coming towards the Spratly Islands. 10 Blue fighter aircraft are patrolling in the region of the Spratly Islands as a first response to engage the adversaries. The Red CVN is in Macau. This can be seen in Figure 126.

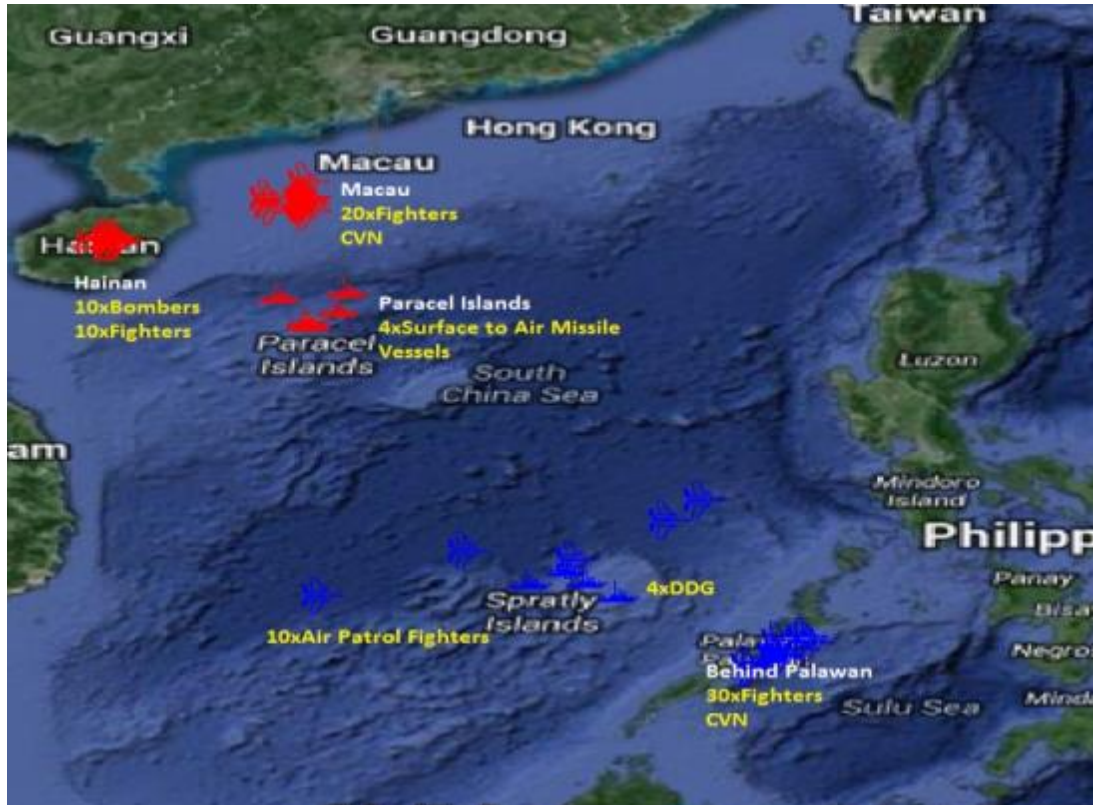


Figure 126. Blue CVN southeast of Palawan, Red CVN in the Sea of Macau.

2. Alternative 2: Blue CVN is Operating Just North of the Spratly Islands

The Blue CVN is operating just north of the Spratly Islands. 30 fighter aircraft are carried by the Blue CVN and are launched at 30 second intervals to counter the Red forces coming towards the Spratly Islands. 10 Blue fighter aircraft are patrolling in the region of Spratly Islands as a first response to engage the adversaries, as depicted in Figure 127.

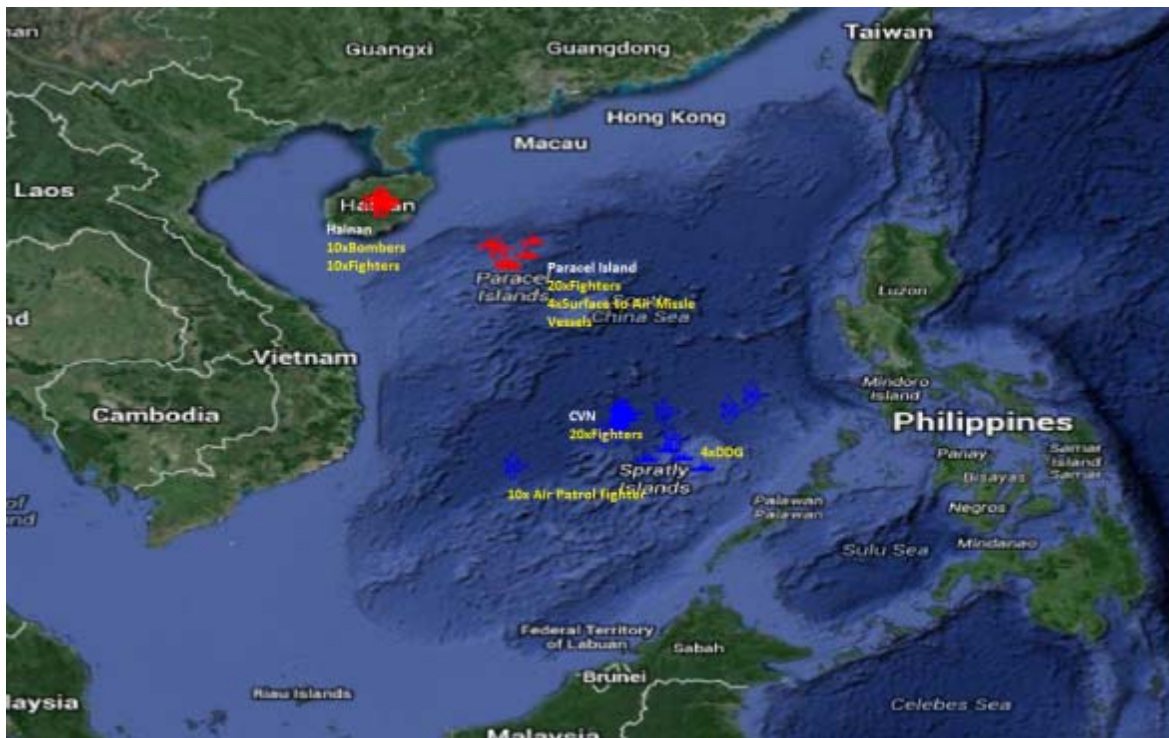


Figure 127. Blue CVN north of Spratly Islands, Red CVN near Paracel Islands.

3. Alternative 3: DAW Concept

The DAW concept of operations disperses the 30 Blue fighter aircraft across two locations. Eight of the 30 Blue fighter aircraft are dispersed across three locations in Vietnam. Another 12 of the 30 Blue fighter aircraft are dispersed across four locations in the Philippines. The last 10 of the 30 Blue fighter aircraft are patrolling in the region of the Spratly Islands as a first response to engage the adversaries. This can be seen in Figure 128.



Figure 128. DAWO Concept.

F. SIMULATED ENEMY SCENARIO 1

The Red CVN is deployed near the Paracel Islands and also launches 20 aircraft at 30 second intervals. They are assisted by 10 fighter sorties, also launched at 30 second intervals. The Red bombers follow behind the fighters and are launched after all fighter aircraft are launched. Their aims are to breakup or destroy the DDGs and Blue ships protecting the Spratly Islands to pave the way for their main forces to attack.

G. SIMULATED ENEMY SCENARIO 2

The Red CVN is now operating in the Sea of Macau. Here the Red forces have their DDGs patrol the Paracel islands instead of using the CVN for that purpose. The CVN launches 20 aircraft at 30 second intervals. They are assisted by 10 fighter sorties, also dispatched at 30 second intervals. The Red bombers follow behind the fighters and are launched after all fighter aircraft are launched. Their aims are to breakup or destroy the Blue DDGs and ships protecting Spratly Islands to pave the way for their main Red forces to attack.

H. SCENARIO PARAMETERS

	Fighters	Bombers	DDGs
Radar Max Effective Range	120km	120km	50km
Weapon Max effective Range	90km	50km	30km
Average speed	300m/s	300m/s	stationary
Maximum time to operate	1 hour	1 hour	unlimited
Air to Air missiles	4	0	0
Air to Surface Missiles	0	4	0
Surface to Air Missiles	0	0	4

Table 38. MANA Scenario parameters.

I. BEHAVIORS

The behaviors of the fighter aircraft are as follows. The fighter aircraft will be launched at 30 second intervals and fall into the default state. In the default state, following the waypoints takes priority over other matters. This is used mainly for the Air Patrol aircraft.

When the Blue aircraft detect any Red enemy in their radar, the default state will transit to the enemy contact state. In this state, the Blue aircraft engages enemies as their top priority and flies towards the enemy target to engage them. Each state takes place for a maximum of 40 minutes, which is the average time before fuel runs out. After the engagement or after 40 minutes, the aircraft move back to their bases for refueling or for repairs. In this maintenance state, the aircraft stay for a minimum of 20 minutes, to simulate the repair and refueling of the aircraft.

Behaviors:

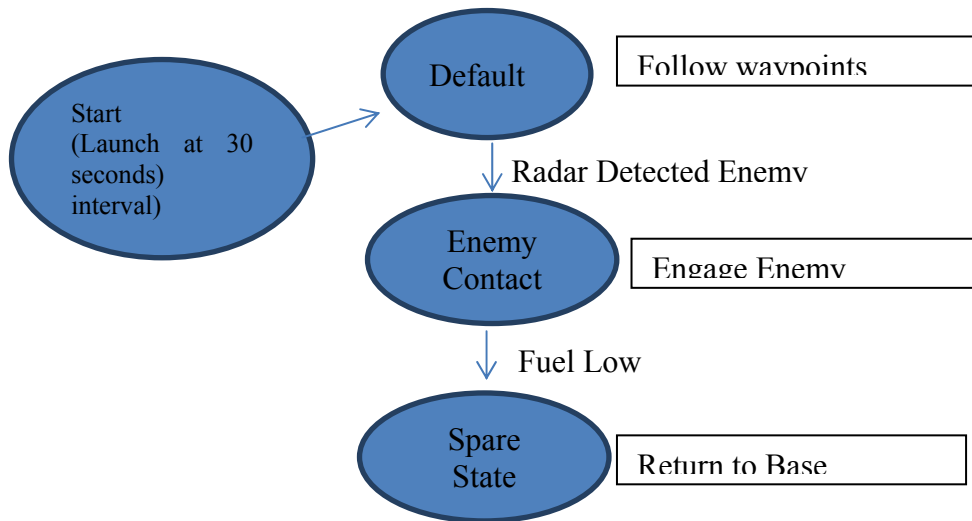


Figure 129. Behavior Flow Chart.

J. RESULTS

1. Scenario 1

Each of the three Alternatives was then tested with 200 simulation runs in each of the two Scenarios. The results for Scenario 1 can be seen in Table 39. Figure 130.

		Scenario 1: Red CVN near Paracel Islands		
		Alternative 1 (CVN South of Palawan)	Alternative 2 (CVN near Spratlys)	Alternative 3 (DAW)
Blue Casualties	Average	27.6	27.6	28.3
	Std. Dev	3.2	3.2	2.7
	95% Conf. Interval	0.45	0.45	0.38
Red Casualties	Average	27.4	27.8	27.1
	Std. Dev	3.3	2.9	3.5
	95% Conf. Interval	0.47	0.40	0.49

Table 39. MANA Scenario 1 results

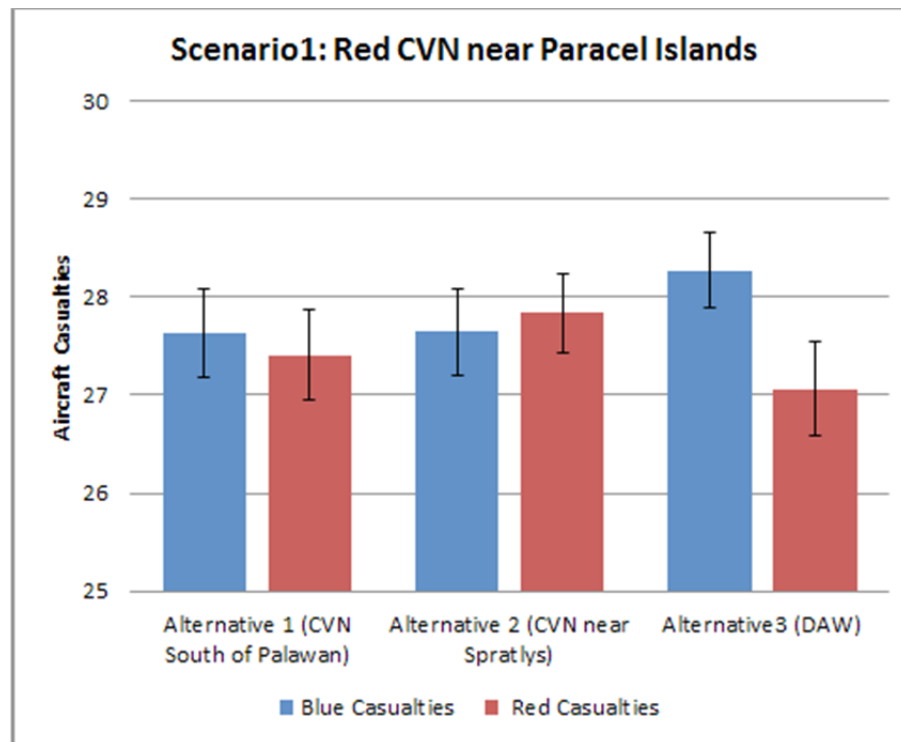


Figure 130. MANA Scenario 1 results.

a. Insights

The DAW spreads its assets to different locations instead of concentrating like the CVN. The experiments runs depicted the red aircraft concentrating their engagements on Vietnam before moving on to engage the Philippines troops. This is a risk that a distributed air wing will need to undertake for spreading their assets widely, into different locations. Hence, the locations nearer to the hostile country will need to be significantly higher.

However, when comparing the results, it showed that the DAW results are not significantly worse off than the CVN alternatives. The number of casualties is about one more when a DAW is utilized. Because of the higher blue casualty rate, the number of red kills is less, though the difference is not statistically significant. Hence, these results showed that the performance of a DAW is comparable to the CVN.

A long-range missile could incapacitate a CVN and could significantly reduce the CVN operating performance. The DAW, with its lesser risks and a comparable performance, is a better choice than the CVN alternatives.

2. Scenario 2

The results for Scenario 2 can be seen in Table 40. and Figure 131.

		Scenario 2: Red CVN in Sea of Macau		
		Alternative 1 (CVN South of Palawan)	Alternative 2 (CVN near Spratlys)	Alternative3 (DAW)
Blue Casualties	Average	27.6	27.0	28.5
	Std. Dev	3.0	3.5	2.7
	95% Conf. Interval	0.43	0.48	0.38
Red Casualties	Average	27.7	27.9	26.1
	Std. Dev	3.2	3.0	3.7
	95% Conf. Interval	0.45	0.42	0.51

Table 40. MANA Scenario 2 results

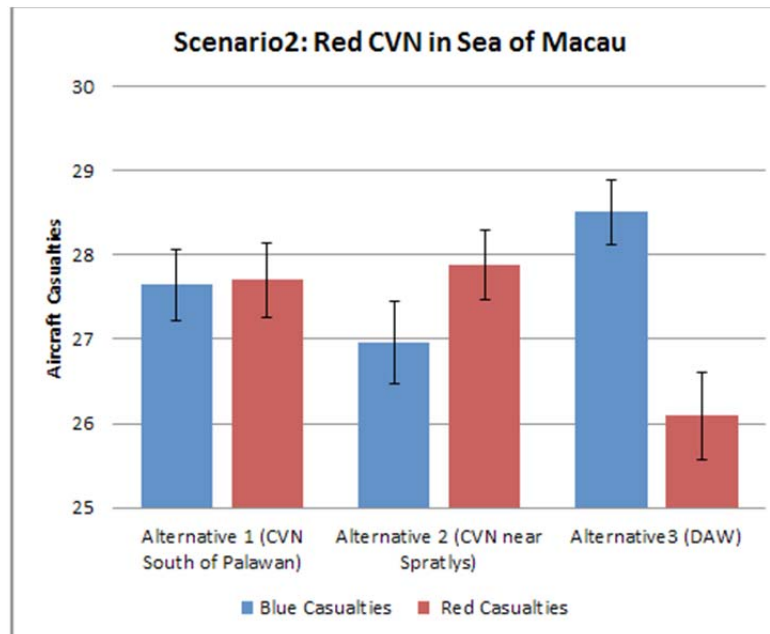


Figure 131. MANA Scenario 2 results

a. Insights

These results show a similar trend of performances. The DAW showed a slight drop in performance compared to the CVN. The difference in mean blue casualties between Alternative 1 and Alternative 3 is statistically significant at the 95% confidence level (P value of 0.003). Similarly the difference in mean red casualties between Alternative 1 and Alternative 3 is statistically significant at the 95% confidence level (P value of 0.000004). Although there is a measured drop in performance, the difference of approximately 1 additional blue aircraft may not be operationally significant. In this scenario, the reaction time for the Vietnam forces to sortie is less because of the close proximity to the Paracel Islands. Furthermore, the blue aircraft are sent on a first launch first engage methodology. This means they do not congregate before moving out to engage the red troops. Hence, the results show that sporadically sending troops to engage a large mass of forces will in fact cause greater losses. This means that despite a distributed concept, it is recommended that forces congregate at a rendezvous point to build up a larger force structure before moving out to engage the large troops.

K. ANALYSIS OF RESULTS

The DAW did result in slightly worse performance than the more concentrated alternatives. However, the difference in casualties is not operationally significant. These results may be explained by the fact that the dispersion of the forces into two locations reduced the size of the effective force in each location.

In the original case, the entire Red force takes on eight Blue in Vietnam then the remaining 23 Blue near the Philippines.

When the CAP is moved to Vietnam, the effective force ratio is about two Red aircraft to one Blue aircraft. This allows 30 Red aircraft to combat 18 Blue in Vietnam then the remaining Red force takes on the last 12 Blue forces in Philippines.

Generally concentrating forces is a better tactic than splitting them into smaller units as happens in this scenario with the DAW. However, when offensive strikes are

required Blue forces can still be concentrated from multiple bases to form a large strike package. Therefore, the slightly worse performance shown here only applies to the defensive counter-air scenarios.

L. LANCHESTER EQUATION ANALYSIS:

Another way to demonstrate the differences observed in this model is by using Lanchester equations. Using a two-staged Lanchester equation to model the engagement, the result can be seen that if the capabilities of the forces are equally matched (i.e., $a = b$), the outcome of the battle will be in Red's favor using the square-law (i.e., aimed-fire.) and a draw if the battle is based on linear-law (i.e., area-fire). This is shown in the following equations.

$$\begin{aligned}
 r &= 30 \text{ Red aircraft}, & b &= 8 \text{ Blue aircraft}, & a &= b = 1, \\
 &\text{for squared law (aimed - fire),} & r &\text{wins since } \frac{r}{b} > \sqrt{\frac{1}{1}} \\
 r_{cap} &= \sqrt{30^2 - \frac{1}{1}(8^2)} = 28.9 \text{ and } r_{final} = \sqrt{28.9^2 - \frac{1}{1}(22^2)} = 18.74, \\
 &\text{for linear law (area - fire), the outcome will be a draw} \\
 &\text{since } r_{cap} = 30 - \frac{1}{1}(8) = 22, \quad r = b = 22 \text{ for the final battle}
 \end{aligned}$$

M. IMPLICATIONS

From the Lanchester equations, a risk pertinent to DAW is the thinning of forces as a result of dispersing the forces. However, the simulation of the scenario shows that both sides suffer almost equal number of casualties and that the battle somewhat follows linear-law. This would suggest that the one disadvantage of the DAW, which is that it lacks the numbers advantage of the CVN, is less crucial than expected. A possible explanation for this observation was that the aircraft has a high single-shot probability of kill; hence one aircraft from each side has equal probability of killing the other at the first shot. Despite the general adherence to Linear Law, it was still observed that there are slightly more Blue casualties than Red.

Another observation is that the bombing of the ships generally takes place after air-superiority is established. Therefore, the key objective of both CVN and DAW operations is to amass as many aircraft in the air to take out the incoming enemy aircraft. With red forces having perfect intelligence information on the location of the blue forces and without any change to the total number of aircraft or capabilities of the aircraft, dispersing the air-wing will not result in any improvement in aerial performance or force-exchange ratio of the DAW. Hence at best, the DAW force structure has the same force-exchange as CVN (assuming Linear Law), but may have degraded performance due to the lower airpower available at each dispersed airbase.

Although this analysis suggests that the DAW Alternative has a worse force-exchange ratio for defensive counter-air missions, this model omits the presence of several other threats including ballistic missiles and submarines that may potentially take out the entire CVN and lead to a catastrophic mission failure. Therefore, although the DAW Alternative goes against the principle of concentration of force, it may still have advantages over the CVN in reducing cost and risk.

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XII. FORCE STRUCTURE COST ESTIMATION AND ANALYSIS

A. FORCE STRUCTURE COST

This section outlines the cost estimation methods and research done in support of the analysis of alternatives. Cost was determined based on the most current data available through conventional DOD cost resources. In most cases, the use of current systems and technology allowed cost to be tabulated through simple research methods. In cases where future or undeveloped systems were utilized, cost estimations were made based on the information available as well as several cost estimating assumptions.

B. ASSUMPTIONS

- All costs are expressed in Fiscal Year 2014 dollars.
- When costs were converted to FY\$14 dollars, the Joint Inflation Indices provided by the Naval Center for Cost Analysis were used.
- Only Unit Costs were used to estimate each alternative force structure's costs and actual replacement costs were not.
- MILCON costs for EABs were given a baseline cost of \$100M that only includes construction of an operational airstrip in the most optimal locations. Manpower, Defense Weapons, Additional Logistics, etc., are not taken into account.
- The LRASM missile is given a baseline price of \$1.3M FY\$14 dollars each (1.3 x the ~\$1M production unit cost of the AGM-158A JASSM missile) due to the infancy of the program and the lack of information on the quantity that will be produced (DOD 2012). Lockheed has cited that it can produce the missile for well under \$2M dollars a unit. (Butler 2013)

C. COST OF CURRENT FORCE STRUCTURE FOR SCS SCENARIO

Table 41 shows a Unit Cost breakdown of this baseline configuration using the average cost of each platform to include a CVN (O'Rourke 2007), LCS (Freedom Class) (Ackerman 2013), LCS (Independence Class) (Ewing 2009), DDG (O'Rourke, Navy DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress 2011), DDX, LHD/LHA (Military Today 2014), LPD (DON 2012), LSD (USN 2013),

SSN (O'Rourke 2014), SSGN (O'Rourke 2006) and JHSV (U.S. Government Accountability Office 2013).

QTY	Platform	Unit Cost	Total Platform Cost
	CSG		
1	CVN	\$ 10,111,602,868.94	\$ 10,111,602,868.94
1	CAW	\$ 5,091,020,242.40	\$ 5,091,020,242.40
6	LCS	\$ 724,346,987.15	\$ 4,346,081,922.90
6	DDGs	\$ 2,422,733,346.21	\$ 14,536,400,077.29
2	DDX	\$ 4,023,133,333.33	\$ 8,046,266,666.67
	ESG		
1	LHD/LHA	\$ 2,504,337,087.19	\$ 2,504,337,087.19
1	ACE	\$ 382,193,552.10	\$ 382,193,552.10
1	LPD	\$ 1,600,000,000.00	\$ 1,600,000,000.00
1	LSD	\$ 425,901,574.42	\$ 425,901,574.42
4	JHSV	\$ 218,066,000.00	\$ 872,264,000.00
3	SSN	\$ 2,707,100,000.00	\$ 8,121,300,000.00
1	SSGN	\$ 5,913,210,305.48	\$ 5,913,210,305.48
	Total Force Cost		\$ 51,838,975,428.44

Table 41. Current Force Structure Costs (FY14\$) for SCS Battle.

Table 41. displays the fact that the main cost driver in the force structure is the CVN at approximately \$10 billion while the SSGN and DDX contribute costs of \$4 billion and \$5.9 billion respectively.

Other than CVN costs, one other element in the CSG that contributed substantially to the total cost is the DDGs. The DDG unit cost of around US\$2 billion is an average cost of 62 DDGs in the fleet. The latest DDG1000 that is being built costs twice as much at around US\$4 billion. Up until now, only three have been budgeted for (O'Rourke 2011). If the DDG1000 proves to be a suitable replacement for all the DDGs in the fleet, the cost of replacement will be substantially higher.

The CVN usually carries more than 75 aircraft while an LHA/LHD will carry approximately 20. The exact configuration can vary dependent on the mission the carrier is assigned.

Table 42 gives the unit costs of F/A-18E/F (DOD 2012), F/A-18C (N) (USN 2009), E-2C (USN 2009), EA-6B (USN 2009), C-2 (USN 2013), MH-60R (DOD 2011), and MH-60S (DOD 2011).

Carrier Air Wing			
QTY	Platform	Variants	Unit Cost FY\$14
15	F/A-18F Super Hornets	F	\$ 69,602,693.10
15	F/A-18E Super Hornets	E	\$ 69,602,693.10
15	F/A-18C Hornet	C	\$ 59,302,743.00
15	F/A-18C(N) Hornet	C(N)	\$ 59,302,743.00
4	E-2C Hawkeye 2000 NP	C	\$ 87,116,094.00
4	EA-6B Prowler	B	\$ 54,100,748.00
3	C-2 Greyhound		\$ 42,425,537.80
4	MH-60F/MH-60H Seahawk	MH-60R	\$ 44,633,117.10
Total		MH-60S	\$ 29,235,211.90
75		Total Cost	\$ 4,707,043,722.40

Table 42. Cost of a possible Carrier Air Wing Configuration

Table 43 gives the Unit Cost of a possible ACE configuration by breaking down the costs of the CH-46 (MilitaryWikia 2014), UH-1 (Federation of American Scientists 2014), AH-1 (MilitaryWikia 2014), CH-53 (Shelf3d.Com 2014), and the AV-8B (U.S. Military 2014).

Air Combat Element (ACE)			
QTY	Platform	Variants	Unit Cost FY\$14
6	CH-46 Sea Knights		\$ 10,688,765.00
2	UH-1 Iroquois		\$ 4,700,000.00
3	AH-1 Cobras		\$ 15,728,000.00
3	CH-53 Super Stallions		\$ 36,192,991.20
4	AV-8B Harriers	B	\$ 40,937,703.50
Total		Total Cost	\$ 393,046,377.60
18			

Table 43. Cost of a common Air Combat Element.

D. EAB BASING COST ESTIMATION

The first of three alternatives investigated was the Dispersed Air Wing - Expeditionary Air Base concept. A force structure composed of six F-35Bs, 2 MQ-8 Fire Scouts, and 2 AEW assets consisting of two variants of the MH-60 were estimated resulting in a cost of over \$1 Billion. This cost is solely the unit or capital cost associated with each aircraft to be stationed at the EAB. Therefore, the number of EABs used will approximately cost over a billion dollars each. Due to the relatively high cost of the EAB force structure, it was assumed that the MILCON cost of the runway would be insignificant in comparison.

Many variables come into play when assessing the construction cost of these EABs. For example, if an EAB was strategically chosen to be built within 100 miles of an already existing Air Force Base, such as Clark Air Base in the Philippines, and the sight was clear of any obstructions such as a thick forest or swampland; its cost would be low compared to a different site. A more expensive proposition would be one where there is not a base within close proximity. A large amount of forestation would need to be cleared, and if it were far inland without roads and supplies, the cost to construct and to maintain the base would be very expensive. Due to the large amount of variables that come in to play when figuring the MILCON cost, a set amount was set aside for this category. After considering factors such as each airstrip will be located in different geographical areas requiring different needs to clear space for construction and locations from ports and resources vastly differing, an arbitrary cost was used for the sake of consistency. It was assumed each base on average may cost approximately \$100M to construct. This does not include defense capabilities such as SAM sites, Surface to Air artillery, etc. Nor does it include the cost of personnel to maintain the equipment and the base itself. This number represents what the team figured to be a reasonable cost to construct the airstrip. Even with a quadrupled EAB cost of \$400M, the total cost of each EAB and the assets that would perform missions from it would still be under \$2Billion for each base.

Table 44 shows the cost breakdown of the F-35B (DON 2013), MQ-8 Fire Scout (Oestergaard 2013), as well as the average cost of the MH-60R (DOD 2012) and MH-60S (DOD 2011).

EAB (Expeditionary Airbase)	QTY	Unit Cost FY\$14	Total Unit Cost FY\$14
F-35B	6	\$ 200,243,519.00	\$ 1,201,461,114.00
MQ-8 Firescout	2	\$ 18,300,000.00	\$ 36,600,000.00
AEW Assets (MH-60S or R)	2	\$ 36,934,164.50	\$ 73,868,329.00
EAB MILCON Cost ~ \$100M	1	\$ 100,000,000.00	\$ 100,000,000.00
		Total Cost	\$ 1,238,061,114.00

Table 44. Single Expeditionary Air Base Cost Analysis

The total cost of the assets needed and the estimated MILCON costs of an EAB were found to be just under \$1.24 Billion each. That cost makes up a mere two percent of the total unit cost of the assets we are trying to replace. If the Dispersed Air Wing EAB concept alone could close the capability gap needed for the scenario then anything less than 50 bases would be a cost saving. That does not include the risk reduction of being destroyed compared to the 26 vessels in the current force structure being analyzed, and the savings of the loss of lives found when operating unmanned aircraft in battle.

E. CVL COST ESTIMATION

Although Light Aircraft Carriers (CVLs) were eliminated from the final force structures recommendations, they were considered as a possible alternative throughout the analysis process.

Since the ship has only been researched (Weisser and Coles-Cieply, Operational Employment of a Light Aircraft Carrier 2009), and there are no plans to build it at this time, the cost estimation team used the latest big deck amphibious ship as an analogous platform for cost. The comparison resulted in a cost of over \$3.6 Billion FY14 to use for the CVL Unit. Table 45. displays the costs of the CVL and its embarked assets. The assets analyzed to deploy with the CVL are the same ones that were analyzed on the EAB alternative. The only differences are the quantities assigned.

Table 45 breaks down the unit cost of the CVL and the assets it would need to conduct the missions needed based on the Team’s analysis by each asset including the Carrier (Weisser and Coles-Cieply, Operational Employment of a Light Aircraft Carrier 2009), F-35B, MQ-8, MH-60R, and the MH-60S.

Platform	QTY	Unit Cost	Total Unit Cost
CVL	1	\$ 3,601,029,018.80	\$ 3,601,029,018.80
16 F-35B	16	\$ 196,500,000.00	\$ 3,144,000,000.00
4 MQ-8	4	\$ 19,100,000.00	\$ 76,400,000.00
3 MH-60R	3	\$ 44,633,117.10	\$ 133,899,351.30
2 MH-60S	2	\$ 29,235,211.90	\$ 58,470,423.80
3 AEW Helo (60R/S)	3	\$ 36,934,164.50	\$ 110,802,493.50
		Total Cost	\$ 7,267,091,507.56

Table 45. CVL and Assets Cost Estimation.

As mentioned previously in the report, the CVL was only an alternative at the start of the Team’s analysis and did not “survive” as an alternative for further analysis based on risk factors attributed to its size and the cost.

F. SEA SCOUT COST ESTIMATION

The 2013 report “Next Generation Fleet Escort Carrier” by the NPS TSSE class outlined the design of a ship designated CVE that could carry UASs into battle (Levine et al. 2013). Though the TSSE design contained many characteristics that were beneficial to for bringing capabilities to the scenario, the overall design was changed to better match the needs determined by the study and therefore, adjustments to the overall cost were applied.

To provide strike capability, the CVE was outfitted with a VLS system and an armament of 56 long range cruise missiles. Implementation of the VLS system resulted in an overall increase in cost to the TSSE design of about \$167M FY14 (DOD 2013). However, the omission of the Electromagnetic Aircraft Launching System from the ship’s design resulted in a reduction in cost of ~\$320M FY14 (Levine et al. 2013).

In regard to long range cruise missiles, the cost of both Tactical Tomahawks and LRASMs were also added to the system (Analysis of the Fiscal Year 2012 Pentagon Spending Request 2013). The LRASM is currently in its early stages of development and will not be awarded for contract until 2018 (Osburn 2014). Since the cost of the LRASM is unknown at this time and the number to be procured is uncertain, a rough figure of 1.3 times the ~\$1Million cost of the JASSM missile, the design that LRASM is based on, was used to formulate a cost of \$1.3Million each to produce the missile.

Another important aspect to the Sea Scout concept is the use of the shelved U.S. Army Hummingbird platform to provide ISR. The cost for the UAV was cited as just under \$4Million each (Wright 2010). Table 46 and Table 47 summarize the overall estimated cost of the Sea Scout system.

Sea Scout Platform (TSSE Design w/Alterations)	Qty	Unit Cost (FY\$14)	Total Unit Cost (FY\$14)
UAV Carrier (TSSE Design)	1	\$ 389,811,658.00	\$ 389,811,658.00
UAV Air Wing			
LRASM	56	\$ 1,300,000.00	\$ 72,800,000.00
A160 Hummingbird	21	\$ 3,889,111.00	\$ 81,671,331.00
VLS Cells	14	\$ 11,932,490.00	\$ 167,054,860.00
		Total Unit Cost	\$ 711,337,849.00

Table 46. Cost using LRASM.

Sea Scout Platform (TSSE Design w/Alterations)	Qty	Unit Cost (FY\$14)	Total Unit Cost (FY\$14)
UAV Carrier (TSSE Design)	1	\$ 389,811,658.00	\$ 389,811,658.00
UAV Air Wing			
Tactical TLAMs	56	\$ 1,535,733.00	\$ 86,001,048.00
A160 Hummingbird	21	\$ 3,889,111.00	\$ 81,671,331.00
VLS Cells	14	\$ 11,935,490.00	\$ 167,096,860.00
		Total Unit Cost	\$ 724,580,897.00

Table 47. Cost Using TLAMs.

The Sea Scout cost tables show that using the LRASM vice the Tactical TLAM would add approximately \$13.2Million in costs. If LRASM were to grow in costs to a high end estimate of \$2Million per missile, a full load-out of LRASM would bring the total cost of the Sea Scout system to up to over ~\$750Million.

Compared to the TSSE design's cost of \$745Million, which includes a BQM air wing (Levine et al. 2013), the redesign of the Sea Vex concept would increase overall capability without adding significantly to the original cost.

XIII. CONCLUSION

A. PROJECT CONCLUSIONS

SEA-20B offers the U.S. Navy three alternatives that can be utilized to mitigate risks associated with operating in an advanced A2AD environment; the Dispersed Air Wing Operations (DAWO) concept, a seaborne unmanned aircraft courier system (Sea Scout), and a carrier/land based unmanned air-to-air fighting vehicle (MTX). Analysis has shown that a combination of these alternatives in varying degrees can deliver the fleet's three most critical capabilities (ISR, Offensive/Defensive Counter Air, and Surface/Land Strike) at less risk than the current CVN/CVW force structure.

DISPERSED AIR WING OPERATIONS

DAWO involves dispersed basing capabilities that can be used to operate carrier aircraft from land bases to project Strike and Counter-Air capability within an A2AD environment. The use of dispersed basing complicates the enemy's targeting and greatly amplifies the resources required for the enemy to put the entire air wing out of action. Operating the CVW in this way reduces risk and allows the full spectrum of Naval Air capabilities throughout the battle space.

These basing options include small scale Expeditionary Airbases (EABs) for Marine Corps STOVL aviation combat elements, Tactical Strike Bases (TSBs) which use dual-purpose highways as runways for conventional-takeoff aircraft from the carrier air wing, and Dispersed Hubs consisting of civilian airfields with hardened and reinforced defenses. These basing options do not require the procurement of new hardware. They only require good relationships with the allied countries in the desired region and personnel with the expertise and the training required to construct such bases.

The advantages and disadvantages of each basing concept were analyzed in detail by SEA-20B. Significant advantages of DAWO were determined to be reduced vulnerability, increased deterrence, and enhanced partnership opportunities with regional nations. Confounding factors are logistical and maintenance complexity and more difficult command and control requirements.

Simulations were conducted and analyzed examining the vulnerability and susceptibility of these bases to attack. Dispersed airbases were shown to be inherently less vulnerable than a CVN. They require significantly more ordnance to achieve neutralization. This is primarily a function of the dispersed parking. It was demonstrated that with a parked aircraft separation distance of 150m, 36 unitary or 28 submunition warheads are required to destroy one-third of an EAB's aircraft with an 80% probability of success. This stands in stark contrast to the damage even a single warhead can cause to a CVW if it impacts a CVN flight deck. Although, not examined in detail, it was also postulated that camouflage and hardening are likely to provide additional vulnerability reduction by decreasing the probability of detection.

SEA SCOUT

Sea Scout is a system-of-systems designed to meet the requirement of distributing airborne ISR, Land Strike and Surface Strike capabilities throughout the fleet. It is comprised of two main elements, a small UAS courier ship and embarked airborne platforms that provide the three primary warfighting capabilities. Whether attached to a SAG or CSG, Sea Scout can deliver persistent distributed capabilities wherever and whenever the fleet needs them the most.

The UAS courier vessel, also known as a CVE, is about 1/3rd the size of a CVN, 1/8th the cost (including acquisition and operation support), and requires only 2% of the CVN/CVW crew. Its small size and speed of up to 50 knots, coupled with point defense capabilities and soft kill measures, make the vessel more difficult to target by A2AD threats and therefore make it more survivable than a CVN.

Sea Scout provides full spectrum ISR capability via the A160 Hummingbird, a rotary wing autonomous UAS platform currently in development by Boeing. While ISR is the Hummingbird's primary mission within the concept, developing capabilities also include small capacity Direct Attack, Communications Relay operations, and Precision Resupply applications. Among the full spectrum of ISR missions, use of the Hummingbird also provides the fleet with over-the-horizon detection and targeting capabilities that enable extended range anti-ship cruise missiles and land attack missiles

to reach their full capability in dynamic targeting scenarios. Its capability is far superior to any platform of its type and weight class boasting a 222 knot maximum speed, a 2,500nm range, 20hr endurance, 2,500lb payload capacity and a full complement of integrated sensors.

Strike capability is designed into Sea Scout with the utilization of current and emerging state-of-the-art cruise missile technology via the Tactical Tomahawk Land Attack Missile (TLAM) and the Long Range Anti-Ship Missile (LRASM). These platforms are integrated into the system by the use of 14 Mk 57 next generation Vertical Launch Systems. With the Mk 57, Sea Scout brings a tailored mixture of up to 56 strike missiles to the fight.

Sea Scout was designed with the capacity for growth. The CVE itself has the space to integrate more platforms, and the Hummingbird has room to integrate increased sensor and weapon capabilities as well. Therefore, as UAS technologies improve, more critical capabilities such as Electronic Warfare, Mine Warfare and Anti-Submarine Warfare could be added in later increments of the system. With potential for growth and the rapid advancement of UAS technology, initial Sea Scout capabilities can be upgraded often in future iterations.

MTX MISSILE-TRUCK UAV

MTX is a two-phase incremental system of unmanned aircraft capable of carrying air-to-air missiles to accompany manned aircraft on fighter missions and providing persistent on-station time for offensive and defensive counter-air missions. The MTX “Missile-Truck UAV” can be paired with a manned fighter for OCA or ISR missions or controlled by an operator from the ground for DCA missions. The concept of the MTX adds three important elements that will aid in closing the capability gaps that are present when the CVN is distant from the fight. First, it reduces risk to personnel by replacing several manned aircraft required to perform the same mission. Second, it increases the payload available to manned fighters allowing the ability to engage more targets. Finally, MTX will provide an increase in combat range by eliminating weight and adding extra fuel tanks.

Three options were considered for the MTX concept. First, an unmanned fighter (QF/A-18 or QF-16), is the quickest and cheapest solution. It can fill the OCA capability gap as long as dispersed air bases are available for deployment. Second, an upgraded version of the MQ-9 Reaper (MQF-X) could fill the dedicated DCA role in protecting high value assets, but it would need some costly modifications. Finally, the X-47B UCAS brings greater range and endurance that is highly desirable in the A2AD environment. However, it would come at a greater price and require a longer lead-time for procurement. Therefore, a phased-in approach based on technology readiness and operational necessity should be taken into account when acquiring these systems.

FORCE STRUCTURE OPTIMIZATION

The integer linear program developed to optimize the locations and quantities of the different force structure alternatives provides a high-level view of the problem. It shows how current carrier strike groups can be combined with Sea Scouts and dispersed bases to provide the optimal mix of capabilities for any future scenario. These optimal force structures can only be built if component platforms are in the Navy's inventory. Therefore, it is critical to begin the process of acquiring an unmanned ISR system now so that they will be available for future conflicts. Similarly, the training and organization required to construct and utilize dispersed bases should begin now.

The team concludes that nuclear powered aircraft carriers need not be eliminated from the U.S. Navy force structure. They provide unrivaled power projection capabilities. However, in order to ensure that their might can be brought to bear on future adversaries, the current force structure must be augmented by distributed capabilities that can mitigate risk inside of an A2AD environment. The analysis in this report shows how the Distributed Air Wing concept can accomplish just that.

B. Further Research Efforts

While the team was able to explore and deliver a broad range of high level Distributed Air Wing concepts, the depth to which the options could be explored was limited due to the time available. There are several areas that must be explored in order to help determine the full potential and feasibility of each concept.

The following items represent general overarching research that would benefit all of the concepts presented.

1. Logistics

The function of providing logistics is an immensely important and intricate piece to conducting operations and must be explored in order to help determine the true cost and feasibility of each alternative. DAWO represents an especially challenging concept for logistics with logistical support requirements spread across an expansive area.

2. Human Systems Integration

Very little consideration was given within this study to Human Systems Integration (HSI). However, HSI should be heavily integrated into the Systems Engineering process throughout the acquisition life-cycle in order to optimize the system outputs. Going forward, a significant effort should be placed across all HSI domains.

Manpower

The number of people needed to man a system is a tremendous driver to the overall system cost. Conducting frequent manning analysis early and often during the system development will help ensure two things. First, it will make certain that the number of people needed to man the system is accurate. Second, it will help provide feedback to the Human Factors Engineering design as the engineers strive to optimize the human/system interface.

(1) Personnel. Choosing the right people with the right skill and experience to operate a system is another aspect that is very important. Bringing more UAS technology into the force structure requires a well thought out assessment of personnel selection. This is especially true as technology matures and UAS vehicles become more and more

autonomous. Presently, UASs in the Navy are controlled by aviators who require expensive training. However, as autonomy progresses and less unique skills and experience are needed to operate these systems, utilization of these highly trained and skilled individuals may not be necessary. The creation of a new officer designator or Navy Enlisted Classification may be prudent to free naval aviators up for flight duties and allow for UAS operators who require less stringent training requirements.

(2) Training. Given the infancy of the U.S. military integration of UAS technology, training systems and methods are still very early in their development. Emphasis on the Training domain will ensure that this newly established group of specialized operators, maintainers and support personnel are efficiently and effectively trained.

(3) Human Factors Engineering. The application of Human Factors Engineering will be critical as the system design matures. As UAS and shipboard systems strive to become more autonomous and allow fewer humans to control greater capacities of assets, the human/system interfaces must be engineered to allow for efficient and accurate interactions. Engineering usability is an immensely important aspect of UAS control design.

(4) Environment, Safety, Occupational Health (ESOH), Survivability and Habitability. While a great deal of the design focuses on unmanned systems and a move towards varying levels of system autonomy, the human will never be left entirely out of the loop. Therefore, ESOH, Survivability and Habitability will always play crucial roles in system design. These domains address a wide range of design aspects ranging from ergonomics and providing comfort to ensuring a safe work environment on the flight deck. Investing time on ESOH, Survivability and Habitability will pay dividends in the long run by reducing medical and disability payments that lead to substantial future cost-burdens.

3. C4I

A serious challenge exists in regard to electronic warfare and the ability to utilize the electromagnetic (EM) spectrum. Modern command and control systems rely heavily on the EM spectrum and are integral to the success of the overall force structure. While

communications challenges were discussed throughout the project timeline, a more in depth study should be conducted to consider solutions to this type of denial in regard to the force structures posed within this study.

4. Foreign Policy

A key enabler for the DAWO concept is having close foreign allies that will allow the United States to build and utilize bases of varying size, location and capacity. That, however, is not a certainty. Going forward, regional foreign policy and relation experts should explore the feasibility of making basing arrangements and develop a long-term strategy to building the relationships necessary for the concept's success. By doing this now, foreign relationships can be strengthened through the construction of dual-purpose infrastructure and military-to-military training. This will allow the DAWO assets to flow into and out of theater when the time is right instead of waiting for lengthy political negotiations to conclude.

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APPENDIX A. FACTOR RANKING DEFINITIONS AND CHARTS

This appendix includes recaps of the four scenarios generated, the factor rankings calculation tables for scenario selection, and factor definitions, referenced in Chapter IV Sections A-B.

A. SCENARIO RECAPS

Scenario 1: South China Sea - A2AD OPERATIONS
China reasserts its maritime claims on Spratlys
Increasing tensions between China, Indonesia, Vietnam and Philippines
Small skirmishes and several ships sunk by both sides
China threatens closure of south china sea as national waters. A2AD environment enacted
U.S. prepares for war at sea strategy to restore freedom of the seas
China fires upon U.S. warships
US executes war at sea strategy not to include strikes on mainland china
US establishes expeditionary airbases in allied territory
US support potential amphibious assaults on islands as needed.
Marines move in to secure the beach in support of allies
Scenario 2: Tensions with Iran - PRECISION STRIKE CAMPAIGN
Increased tensions with Iran over nuclear program
Outbound: US carrier group in Bahrain getting repairs and Iran announced closing of straits to US Ships.
Need to get the carrier group out
Provide air support to escort carrier out
Distributed air wing is already operating in the Gulf of Oman
Sea screening ahead of carrier group from the Gulf of Oman
Iran attempts attacks on carrier with swarm tactics and mini subs
DAW and carriers support full scale aerial operations
Precision strikes on WMD facilities and air defense sites
Scenario 3: Philippines - HUMANATARIAN ASSISTANCE
Typhoon hits Philippines
Assist International coalition with aid.
Using the DAW to repel warlords from "snatching and keeping the supplies for themselves"
Scenario 4: North Korea - FULL SCALE WAR
Tensions rise between North and South Korea over a shared industrial zone
North Korea sinks one of their own ships near the DMZ and blames South Korea to instigate war
The North Koreans then move to the offensive launching naval and aerial actions against South Korea.
As military actions on both sides escalate, the United States is called upon to aid in the defense of its ally
Forces mobilize on DAW land bases and at sea and are attacked by North Korean ballistic missiles/ small subs
US builds up military pressure against North Korean government and military forces
WMDs are used against American military targets in the Pacific and civilian South Korean targets
The US continues to fight through the atrocities and finally manages to bring down the dictatorship

B. SCENARIO FACTOR RANKINGS

	Scenario					
Mission Capability Factors	South China Sea - A2/AD Battles	Iran - Precision Strike	Philippines - Humanitarian	North Korea - Full Scale War	Factor Average	Overall Rank
Timeliness	3	4.5	5	3	3.88	12
Communications	5	3	3	5	4.00	8
Comm. Range	4	2	4	5	3.75	13
Comm. robustness/redundancy	5	3	3	5	4.00	8
Comm Security	5	4	1	4.5	3.63	14
Intelligence	4.5	5	4	4.5	4.50	2
Organic ISR	4.5	5	4	4	4.38	3
External Intelligence	4.5	5	5	5	4.88	1
Force Readiness Capability	5	4.5	3.5	4	4.25	5
Training	5	5	3	3.5	4.13	7
Manpower	5	4	4	4	4.25	5
Accessibility and Availability of Deployable Assets	5	4	3.5	5	4.38	3
Long Range Logistics	5	2	5	4	4.00	8
Theater Logistics	4	3	5	2	3.50	15
Force Scalability	4	3.5	3	3	3.38	16
Force Distribution	5	4	3.5	3.5	4.00	8
Scenario Average	4.6	3.8	3.7	4.1		
Scenario Ranking	1	3	4	2		
Weapons/Warfare Requirement Factors						
Electronic/Cyber Warfare	4.5	3.0	1.0	4.0	3.13	3
Close Air Support	2.0	2.0	1.0	3.5	2.13	7
Anti Aircraft Capability	4.5	2.0	1.0	3.0	2.63	5
Anti- Missile Capability	4.0	5.0	1.0	3.0	3.25	2
BMD and Anti-Ballistic Missile Capability	4.0	5.0	1.0	5.0	3.75	1
Deep Strike Capability	2.0	4.5	1.0	4.0	2.88	4
MIW Capability	2.0	4.0	1.0	2.0	2.25	6
Scenario Average	3.3	3.6	1.0	3.5		
Scenario Ranking	3	1	4	2		
Geo-Political Scenario Factors						
Geography, Oceanography, Environmental Factors	4.5	4.5	4.0	5.0	4.50	1
International and/or Joint Cooperation and Support	4.0	2.5	4.5	4.0	3.75	2
Govt. Interoperability with other Govt/ NGO agencies	3.0	3.0	4.0	4.5	3.63	3
Scenario Average	3.8	3.3	4.2	4.5		
Scenario Ranking	3	4	2	1		
Overall Scenario Average	4.2	3.7	3.0	4.0		
Overall Scenario Ranking	1	3	4	2		

C. SCENARIO FACTOR DEFINITIONS

Mission Capability Factors	Factor Amplification
Timeliness	Defined as the timeliness capability of execution of orders, and reaction time needed to accomplish the mission
Communications	Defined as the communication capabilities including range, robustness and redundancy of communication systems and infrastructure, security of communication needed to accomplish the mission
Comm. Range	Defined as the communication range between forces needed to accomplish the mission.
Comm. robustness/redundancy	Defined as the requirements of having a robust system in order for forces to communicate 24x7 in order to accomplish the mission. Redundancies are usually included to boost the system readiness to prevent breakdown of communication should a critical system fail in order to accomplish the mission.
Comm Security	Defined as the communication security requirements of a system.
Intelligence	Defined as the ISR capabilities, including range, coverage, organic and external capabilities needed to accomplish the mission.
Organic ISR	Defined as the organic Intelligence, Surveillance, Reconnaissance (ISR) capabilities included in the systems onboard the platforms needed to accomplish the mission.
External Intelligence	Defined as the ability to collect intelligence data outside of platforms in order to accomplish the mission. These data could be collected from intelligence agencies from external organizations, e.g. CIA, ARMY, etc. or from affiliates of NAVY.
Force Readiness Capability	Defined as the accessibility and availability of deployable assets, personnel, manpower requirements, maintenance capabilities, long range logistics support and theater logistics support needed to accomplish the mission.
Training	Defined as the level of training or importance of training needed to build up the skillsets needed to accomplish the mission.
Manpower	Defined as the number of troops / specialty skill sets that are needed to accomplish the mission. A large scale major operation vs. small scale mission
Accessibility and Availability of Deployable Assets	Defined as the accessibility (in terms of use) and availability (in terms of maintenance) of a platform or set of assets to be able to deploy and execute the mission.
Long Range Logistics	Defined as the ability to coordinate/support long range logistics
Theater Logistics	Defined as the ability to coordinate/support the demands of a large scale deployment or troops. (>500,000 troops)
Force Scalability	Defined as the ability of forces to expand or scale down their size quickly in order to accomplish the mission.
Force Distribution	Defined as the ability of forces to be able to distribute into smaller forces or deploy/disperse into different units/locations in order to accomplish their mission.
Weapons/Warfare Requirement Factors	
Electronic/Cyber Warfare	Defined as the requirement of forces to provide EW attacks and defend against EW/Cyber
Close Air Support	Defined as the requirement of having close air support to support the ground forces, transporting the troops to their deployment sites or supply logistics materiel to the ground troops in order to accomplish the mission.
Anti Aircraft Capability	Defined as the requirement of having air-defense capabilities to defend against air threats needed to accomplish the mission
Anti- Missile Capability	Defined as the requirement of having the ability to defend against air, land or surface missiles in order to accomplish the mission.
BMD and Anti-Ballistic Missile Capability	Defined as the requirement of having the ability to conduct BMD or defend against ballistic missiles in order to accomplish the mission.
Deep Strike Capability	Defined as the requirement of having ground troops move deep into hostile territory to take down critical hostile assets, personnel or operating environment needed to accomplish the mission
MIW Capability	Defined as the requirement of having the ability to counter against mine warfare in order to accomplish the mission.
Geo-Political Scenario Factors	
Geography, Oceanography, Environmental Factors	Defined as the challenging port/base locations, difficult terrain/waterways, and environmental hazards near the theater/area of operations that could affect the
International and/or Joint Cooperation and Support	Defined as the political and material support from allies or other armed services (Air Force, Army, Coast Guard, Special Ops, and Marines) needed to accomplish the mission.
Govt. Interoperability with other Govt/ NGO agencies	Defined as the need for multiple agencies: govt. / non-govt. to operate together in order to accomplish the mission

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APPENDIX B. EAB PROTECTION FIGURES AND RESULTS

In this annex the figures for the EAB layout that were tested in Chapter VII Section B.4 are shown. Each Blue dot in a plot marks the location of an aircraft. Note that in some plots not all six aircraft are visible within the area shown in the plot. However, all six are accounted for in the simulation.

The red dots mark the strike points of incoming missiles. 2000 of these locations are shown to allow the reader some intuition as to the distribution of the strikes.

The yellow circle marks the center of the nine-point square that the enemy uses for targeting. It is essentially the center of the distribution of incoming missile strikes.

A. EXAMPLE GRAPHICAL RESULTS (FIGURE 3, 4, AND 5 OF 25 TOTAL)

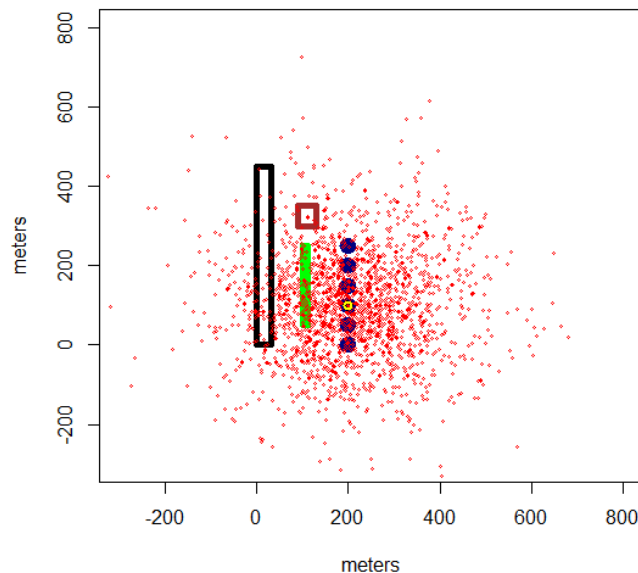


Figure 3: Single row A/C parking design without camouflage (enemy targets A/C). Aircraft spacing is 50 meters.

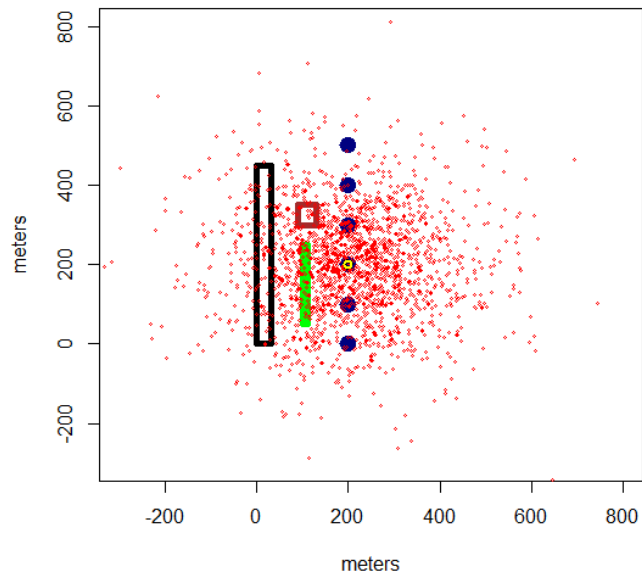


Figure 4: Single row A/C parking design without camouflage (enemy targets A/C). Aircraft spacing is 100 meters.

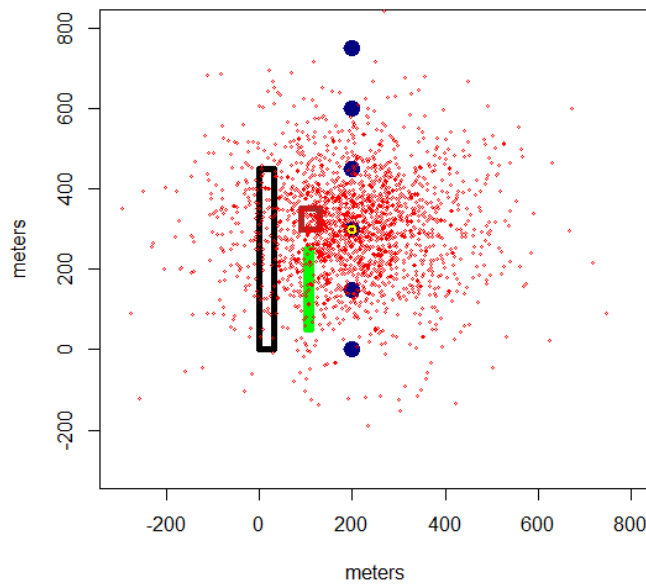


Figure 5: Single row A/C parking design without camouflage (enemy targets A/C). Aircraft spacing is 150 meters.

B. EAB PROTECTION SIMULATION CODE

The following code was developed to create the Simulation model described in Chapter VII Section B.4 for locating the incoming strikes in a salvo, and comparing it to the layout of an EAB. This code was implemented in R.

```
#upper bound analytic
mslstd=100
lethalR=575*.3
phit=1-exp(-lethalR^2/(2*mslstd^2))
p2hit=1-(1-phit)^2
1-pbinom(1,6,p2hit)

#lower bound analytic
lethalR=575*.3
l=1000
n=round(l/lethalR)^2
1-phyper(1,6,n-6,12)

lethalR=206*.3
n=round(l/lethalR)^2
1-phyper(1,6,n-6,12)

#simulation
#all units are meters
#number of runs
n=1*10^6

#EAB layout
#item location are in order of (bottom left x,bottom left y, top right x, top right y)
runway=c(0,0,30,450)
truck=c(90,300,130,350)
personnel=c(100,50,110,250)

space=200
#two-row design
#acl=c(30,0,30,0)
#ac2=c(30,space,30,space)
#ac3=c(30,2*space,30,2*space)
#ac4=c(30+space,0,30+space,0)
#ac5=c(30+space,space,30+space,space)
#ac6=c(30+space,2*space,30+space,2*space)

#one row design
acl=c(200,0,200,0)
ac2=c(200,space,200,space)
ac3=c(200,2*space,200,2*space)
ac4=c(200,3*space,200,3*space)
ac5=c(200,4*space,200,4*space)
ac6=c(200,5*space,200,5*space)

#enemy capabilities
salvo=10 #salvo size
X=15 #aimpoint x
Y=200 #aimpoint y
lethalradius=575*.3 #lethal radius of missile (206 for unitary, 575 for bomblets)
targeting_range=3000
targeting_accuracy=50/1000*targeting_range #targeting accuracy
bm_accuracy=100 #ballistic missile accuracy
aimpoint=matrix(c(rep(c(X,X,X,X,lethalradius+X,lethalradius+X,lethalradius+X,X-
lethalradius,X-lethalradius,X-lethalradius),n/10),rep(c(Y,Y,Y+lethalradius,Y-
lethalradius,Y,Y+lethalradius,Y-lethalradius,Y,Y+lethalradius,X-lethalradius),n/10)),n,2)

#find strikepoints
```

```

range_error=rnorm(n,sd=targeting_accuracy)
direction_error=runif(n,max=2*pi)
actual_aimpoints=aimpoint+matrix(c(range_error*cos(direction_error),range_error*sin(direction_error)),n,2)
range_error=rnorm(n,sd=bm_accuracy)
direction_error=runif(n,max=2*pi)
strikepoints=actual_aimpoints+matrix(c(range_error*cos(direction_error),range_error*sin(direction_error)),n,2)

#find how many hits have been suffered
x=strikepoints[,1]+lethalradius>runway[1] & strikepoints[,1]-lethalradius<runway[3]
y=strikepoints[,2]+lethalradius>runway[2] & strikepoints[,2]-lethalradius<runway[4]
q=Matrix(x&y,n/salvo,salvo)
w=apply(q,1,sum)
phit_runway_salvo=nnzero(w)/n*salvo
numhit_runway_salvo=mean(w)

x=strikepoints[,1]+lethalradius>ac1[1] & strikepoints[,1]-lethalradius<ac1[3]
y=strikepoints[,2]+lethalradius>ac1[2] & strikepoints[,2]-lethalradius<ac1[4]
q=Matrix(x&y,n/salvo,salvo)
w=apply(q,1,sum)
phit_ac1_salvo=nnzero(w)/n*salvo
numhit_ac1_salvo=mean(w)

x=strikepoints[,1]+lethalradius>ac2[1] & strikepoints[,1]-lethalradius<ac2[3]
y=strikepoints[,2]+lethalradius>ac2[2] & strikepoints[,2]-lethalradius<ac2[4]
q=Matrix(x&y,n/salvo,salvo)
w=apply(q,1,sum)
phit_ac2_salvo=nnzero(w)/n*salvo
numhit_ac2_salvo=mean(w)

x=strikepoints[,1]+lethalradius>ac3[1] & strikepoints[,1]-lethalradius<ac3[3]
y=strikepoints[,2]+lethalradius>ac3[2] & strikepoints[,2]-lethalradius<ac3[4]
q=Matrix(x&y,n/salvo,salvo)
w=apply(q,1,sum)
phit_ac3_salvo=nnzero(w)/n*salvo
numhit_ac3_salvo=mean(w)

x=strikepoints[,1]+lethalradius>ac4[1] & strikepoints[,1]-lethalradius<ac4[3]
y=strikepoints[,2]+lethalradius>ac4[2] & strikepoints[,2]-lethalradius<ac4[4]
q=Matrix(x&y,n/salvo,salvo)
w=apply(q,1,sum)
phit_ac4_salvo=nnzero(w)/n*salvo
numhit_ac4_salvo=mean(w)

x=strikepoints[,1]+lethalradius>ac5[1] & strikepoints[,1]-lethalradius<ac5[3]
y=strikepoints[,2]+lethalradius>ac5[2] & strikepoints[,2]-lethalradius<ac5[4]
q=Matrix(x&y,n/salvo,salvo)
w=apply(q,1,sum)
phit_ac5_salvo=nnzero(w)/n*salvo
numhit_ac5_salvo=mean(w)

x=strikepoints[,1]+lethalradius>ac6[1] & strikepoints[,1]-lethalradius<ac6[3]
y=strikepoints[,2]+lethalradius>ac6[2] & strikepoints[,2]-lethalradius<ac6[4]
q=Matrix(x&y,n/salvo,salvo)
w=apply(q,1,sum)
phit_ac6_salvo=nnzero(w)/n*salvo
numhit_ac6_salvo=mean(w)

x=strikepoints[,1]+lethalradius>truck[1] & strikepoints[,1]-lethalradius<truck[3]
y=strikepoints[,2]+lethalradius>truck[2] & strikepoints[,2]-lethalradius<truck[4]
q=Matrix(x&y,n/salvo,salvo)
w=apply(q,1,sum)
phit_truck_salvo=nnzero(w)/n*salvo
numhit_truck_salvo=mean(w)

x=strikepoints[,1]+lethalradius>personnel[1] & strikepoints[,1]-lethalradius<personnel[3]
y=strikepoints[,2]+lethalradius>personnel[2] & strikepoints[,2]-lethalradius<personnel[4]
q=Matrix(x&y,n/salvo,salvo)

```

```

w=apply(q,1,sum)
phit_personnel_salvo=nnzero(w)/n*salvo
numhit_personnel_salvo=mean(w)

numhit_runway_salvo
numhit_ac1_salvo
numhit_ac2_salvo
numhit_ac3_salvo
numhit_ac4_salvo
numhit_ac5_salvo
numhit_ac6_salvo
numhit_truck_salvo
numhit_personnel_salvo
phit_runway_salvo
phit_ac1_salvo
phit_ac2_salvo
phit_ac3_salvo
phit_ac4_salvo
phit_ac5_salvo
phit_ac6_salvo
#chance for at least 1 ac to be hit
1-(1-phit_ac1_salvo)*(1-phit_ac2_salvo)*(1-phit_ac3_salvo)*(1-phit_ac4_salvo)*(1-
phit_ac5_salvo)*(1-phit_ac6_salvo)
#chance for at least 2 ac to be hit
1-(1-phit_ac1_salvo)*(1-phit_ac2_salvo)*(1-phit_ac3_salvo)*(1-phit_ac4_salvo)*(1-
phit_ac5_salvo)*(1-phit_ac6_salvo)-phit_ac2_salvo*(1-phit_ac1_salvo)*(1-
phit_ac3_salvo)*(1-phit_ac4_salvo)*(1-phit_ac5_salvo)*(1-phit_ac6_salvo)-
phit_ac1_salvo*(1-phit_ac2_salvo)*(1-phit_ac3_salvo)*(1-phit_ac4_salvo)*(1-
phit_ac5_salvo)*(1-phit_ac6_salvo)-phit_ac3_salvo*(1-phit_ac2_salvo)*(1-
phit_ac1_salvo)*(1-phit_ac4_salvo)*(1-phit_ac5_salvo)*(1-phit_ac6_salvo)-
phit_ac4_salvo*(1-phit_ac2_salvo)*(1-phit_ac3_salvo)*(1-phit_ac1_salvo)*(1-
phit_ac5_salvo)*(1-phit_ac6_salvo)-phit_ac5_salvo*(1-phit_ac2_salvo)*(1-
phit_ac3_salvo)*(1-phit_ac4_salvo)*(1-phit_ac1_salvo)*(1-phit_ac6_salvo)-
phit_ac6_salvo*(1-phit_ac2_salvo)*(1-phit_ac3_salvo)*(1-phit_ac4_salvo)*(1-
phit_ac5_salvo)*(1-phit_ac1_salvo)
phit_truck_salvo
phit_personnel_salvo

plot(c(runway[1],runway[1],runway[3],runway[3],runway[1]),c(runway[2],runway[4],runway[4],
runway[2],runway[2]),type="l",xlab="meters",ylab="meters",col="black",xlim=c(-
300,800),ylim=c(-300,800),lwd=5)
points(c(ac1[1],ac2[1],ac3[1],ac4[1],ac5[1],ac6[1]),c(ac1[2],ac2[2],ac3[2],ac4[2],ac5[2],
ac6[2]),col="navy blue",lwd=8)
lines(c(truck[1],truck[1],truck[3],truck[3],truck[1]),c(truck[2],truck[4],truck[4],truck[
2],truck[2]),col="brown",lwd=5)
lines(c(personnel[1],personnel[1],personnel[3],personnel[3],personnel[1]),c(personnel[2],
personnel[4],personnel[4],personnel[2],personnel[2]),col="green",lwd=5)
points(strikepoints[1:2000,],col="red",cex=.4)
points(aimpoint[1,1],aimpoint[1,2],col="black",lwd=3)
points(aimpoint[1,1],aimpoint[1,2],col="yellow",lwd=2)

```

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APPENDIX C. GAMS CODE

A. GAMS CODE: MINIMIZE RISK

This appendix includes the GAMS code for the minimize risk ILP described in Chapter X.

```
$TITLE South China Sea Basing Optimization Model

$Offlisting
$set datapath %gams.user1%
*-----GAMS AND DOLLAR CONTROL OPTIONS-----
$OFFUPPER OFFSYMLIST OFFSYMREF
$ONEMPTY
$inlinecom{ }

OPTIONS
    LIMROW    = 0
    LIMCOL    = 0
    ITERLIM   = 1000000
    RESLIM    = 100000
    SOLPRINT  = OFF
    DECIMALS  = 2
    LP        = cplex
    RMIP      = cplex
    MIP       = cplex
    OPTCR     = 0.0
;

*-----

$ONTEXT
    Authors : E. Wolfe, M. Ng, I Bar-Ilan
              Systems Engineering and Analysis
              Naval Postgraduate School
              Monterey, California 93943
              ewolfe@nps.edu

    Original: January 2014 E. Wolfe

    Description: The South China Sea Basing Optimization Model prescribes an optimal
    basing plan for the Navy by determining the quantity and locations of Aircraft Carriers
    (CVNs), Light Aircraft Carriers (CVLs), UAV Carriers (Sea Scout) and expeditionary
    airbases (EABs) to cover specified mission sets in the South China Sea for minimal risk.

$OFFTEXT

*-----Indices-----

SETS
    i hexagonal regions of South China Sea /1*4266/ ;

ALIAS    (i,j) ;

SET      iSea(i) subset of regions containing water suitable for ships;

SET      iSea
/
$ondelim
$include seaSubset.csv
$offdelim
/
```

```

;

SET      iLand(i) subset of regions containing land suitable for EABs;

SET      iLand
/
$ondelim
$include landSubset.csv
$offdelim
/
;

*-----Data-----

Parameter      ISR(j) amount of ISR coverage required by region j [hrs]
/
$ondelim
$include isr3.csv
$offdelim
/
;

Parameter      STRIKE(j) amount of strike capability required by region j [sorties]
/
$ondelim
$include strikel.csv
$offdelim
/
;

Parameter      DCA(j) amount of defensive counter air coverage required by region j [hrs]
/
$ondelim
$include dca3.csv
$offdelim
/
;

Parameter      RISK A(i) amount of risk incurred by an EAB in region i
/
$ondelim
$include riskA1.csv
$offdelim
/
;

Parameter      RISK B(i) amount of risk incurred by a CVL in region i
/
$ondelim
$include riskB1.csv
$offdelim
/
;

Parameter      RISK C(i) amount of risk incurred by a CVN in region i
/
$ondelim
$include riskC1.csv
$offdelim
/
;

Parameter      RISK D(i) amount of risk incurred by a Sea Scout in region i
/
$ondelim
$include riskD1.csv
$offdelim
/

```



```

;

Table                isrA(i,j) the amount of ISR coverage provided by an EAB in region i to
region j [hrs]

$ondelim
$include isrA1.csv
$offdelim  ;

Table                isrB(i,j) the amount of ISR coverage provided by a CVL in region i to
region j [hrs]

$ondelim
$include isrB1.csv
$offdelim  ;

Table                isrC(i,j) the amount of ISR coverage provided by a CVN in region i to
region j [hrs]

$ondelim
$include isrC1.csv
$offdelim  ;

Table                isrD(i,j) the amount of ISR coverage provided by a Sea Scout in region i
to region j [hrs]

$ondelim
$include isrD1.csv
$offdelim  ;

Table                strikeA(i,j) the amount of strike capability provided by an EAB in
region i to region j [sorties]

$ondelim
$include strikeA1.csv
$offdelim  ;

Table                strikeB(i,j) the amount of strike capability provided by a CVL in region
i to region j [sorties]

$ondelim
$include strikeB1.csv
$offdelim  ;

Table                strikeC(i,j) the amount of strike capability provided by a CVN in region
i to region j [sorties]

$ondelim
$include strikeC1.csv
$offdelim  ;

Table                strikeD(i,j) the amount of strike capability provided by a Sea Scout in
region i to region j [sorties]

$ondelim
$include strikeD1.csv
$offdelim  ;

Table                dcaA(i,j) the amount of defensive counter air provided by an EAB in
region i to region j [hrs]

$ondelim
$include dcaA1.csv
$offdelim  ;

Table                dcaB(i,j) the amount of defensive counter air provided by a CVL in
region i to region j [hrs]

```

```

$ondelim
$include dcaB1.csv
$offdelim ;

Table                dcaC(i,j) the amount of defensive counter air provided by a CVN in
region i to region j [hrs]

$ondelim
$include dcaC1.csv
$offdelim ;

SCALAR    CostA cost of an expeditionary base [$ billions]      /1.31/ ;
SCALAR    CostB cost of a CVL [$ billions]                      /7.27/ ;
SCALAR    CostC cost of a CVN [$ billions]                      /10.95/ ;
SCALAR    CostD cost of a Sea Scout [$ billions]                /0.66/ ;

SCALAR    TotalCost total allowable expenses [$ billions]      /30/ ;

SCALAR    crewA the number of personnel at risk at an EAB       /100/ ;
SCALAR    crewB the number of personnel at risk on a CVL        /940/ ;
SCALAR    crewC the number of personnel at risk on a CVN        /4450/ ;
SCALAR    crewD the number of personnel at risk on a Sea Scout   /150/ ;

*-----variables-----

BINARY VARIABLES
    A(iLand)  1 if there is a expeditionary base in region i (0 otherwise)
    B(iSea)   1 if there is a CVL in region i (0 otherwise)
    C(iSea)   1 if there is a CVN in region i (0 otherwise)
    D(iSea)   1 if there is a Sea Scout in region i (0 otherwise)
;

VARIABLE    Z          Total risk;

EQUATION OBJ;

OBJ..
    Z
    =E=
    sum((iLand),A(iLand)*riskA(iLand)*crewA)
    sum((iSea),B(iSea)*riskB(iSea)*crewB)      +
    sum((iSea),C(iSea)*riskC(iSea)*crewC)      +
    sum((iSea),D(iSea)*riskD(iSea)*crewD);

*-----constraints-----

EQUATION CONSTRAINT2;

CONSTRAINT2(iSea)..
    B(iSea)+C(iSea)+D(iSea)
    =L=
    1;

*Constraint2: No ships placed on land
*and no more than one ship in each region

EQUATION CONSTRAINT3;

CONSTRAINT3..
    sum((iLand),A(iLand)*CostA)      +
    sum((iSea),B(iSea)*CostB)      +
    sum((iSea),C(iSea)*CostC)+
    sum((iSea),D(iSea)*CostD)
    =L=
    TotalCost;

*Constraint3: Cost must be less than TotalCost

EQUATION CONSTRAINT4;

```

```

CONSTRAINT4(j)..
        sum((iLand),A(iLand)*isrA(iLand,j))
sum((iSea),B(iSea)*isrB(iSea,j))      +
sum((iSea),D(iSea)*isrD(iSea,j))      +
        =G=
        ISR(j);

*Constraint4: All ISR requirements are met in each region

EQUATION CONSTRAINT5;

CONSTRAINT5(j)..
        sum((iLand),A(iLand)*strikeA(iLand,j))
sum((iSea),B(iSea)*strikeB(iSea,j))    +
sum((iSea),D(iSea)*strikeD(iSea,j))    +
        =G=
        STRIKE(j);

*Constraint5: All strike requirements are met in each region

EQUATION CONSTRAINT6;

CONSTRAINT6(j)..
        sum((iLand),A(iLand)*dcaA(iLand,j))
sum((iSea),B(iSea)*dcaB(iSea,j)) + sum((iSea),C(iSea)*dcaC(iSea,j))
        =G=
        DCA(j);

*Constraint6: All DCA requirements are met in each region

MODEL BOM /ALL/;
SOLVE BOM USING MIP MINIMIZING Z;

* Add display for objective variables and vectors of variables you used
DISPLAY a.l, b.l, c.l, d.l, Z.L ;

```

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APPENDIX D. EXAMPLE CALCULATIONS

This appendix includes example calculations for risk and effectiveness for a CVN described in Chapter X Section C.

A. EXAMPLE CVN RISK CALCULATION AT 750 NM

Bomber Parameters:

$$\text{Max Bomber Range} = 1800 \text{ km} = 972 \text{ nm}$$

$$\text{ASCMS/Bomber} = 4$$

$$\text{Max } P_{\text{Launch ASCMs}} = 0.1$$

$$P_{\text{Hit ASCM}} = 0.4$$

Bomber Calculations:

$$\text{In Bomber Range? } 750 \text{ km} < 972 \text{ nm} \rightarrow \text{YES}$$

$$P_{MK} = P_{\text{Launch ASCMs}} * P_{\text{Salvo Hit|Launch}}$$

$$P_{\text{Salvo Hit|Launch}} = 1 - (1 - P_{\text{Hit ASCM}})^n = 1 - (1 - 0.4)^4 = 0.87$$

$$P_{\text{Launch ASCMs}} = \text{Max } P_{\text{Launch ASCMs}} * \left(1 - \frac{\text{Range}}{\text{Max Bomber Range}}\right) = 0.1 * \left(1 - \frac{750}{972}\right) = 0.023$$

$$P_{MK} = 0.023 * 0.87 = \mathbf{0.02}$$

SSN Parameters:

$$\text{Max SSN Range} = 2500 \text{ km} = 1350 \text{ nm}$$

$$\text{Min SSN Range} = 1000 \text{ km} = 540 \text{ nm}$$

$$P_{\text{Attack|Detection}} = 1.0$$

$$P_{\text{Hit Torpedo}} = 0.8$$

$$P_{\text{Hit ASCM}} = 0.4$$

$$P_{\text{Torpedo Attack|Attack}} = 0.3$$

$$P_{\text{ASCM Attack|Attack}} = 0.7$$

$$\text{Number of SSNs} = 10$$

$$\text{Search Speed (V)} = 7 \text{ kts}$$

$$\text{CVN Speed (U)} = 30 \text{ kts}$$

$$\text{Detection Range} = 5 \text{ nm}$$

$$\text{Search Sector} = 60^\circ$$

Example CVN Risk Calculation at 750 nm continued:

SSN Calculations:

$$P_{MK|Detection} = P_{Attack|Detection} \\ * (P_{Torpedo Attack|Attack} * P_{Hit Torpedo} + P_{ASCM Attack|Attack} * P_{Hit ASCM}) \\ = 1.0 * (0.3 * 0.8 + 0.7 * 0.4) = 0.52$$

$$P_{Detection}(t) = 1 - e^{-\bar{V}Wt/A}$$

$$W = \text{Sweep Width} = 2 * \text{Detection Range} = 2 * 5 \text{ nm} = 10 \text{ nm}$$

$$\bar{V} = \text{relative search speed} \approx \frac{1}{2}(\max(U, V) + \sqrt{U^2 + V^2}) = \frac{1}{2}(30 + \sqrt{7^2 + 30^2}) \\ = 30.4 \text{ kts}$$

$$\text{Total search area} = \pi(\text{Max SSN Range}^2 - \text{Min SSN Range}^2) * \frac{\text{Search Sector}}{360}$$

$$= \pi(1350^2 - 540^2) * \frac{60}{360} = 801,577 \text{ nm}^2$$

$$A = \text{search area per submarine} = \frac{\text{total search area}}{\# \text{ of subs}} = \frac{801,450 \text{ nm}^2}{10} \\ = 80,145 \text{ nm}^2$$

$$t = \text{time} = \text{CVN transit time through search area} + 24 \text{ hours of operation}$$

$$\text{CVN transit time} = \frac{\text{Max SSN Range} - \text{Range}}{\text{CVN Speed}} = \frac{1350 \text{ nm} - 750 \text{ nm}}{30 \text{ kts}} = 20 \text{ hrs}$$

$$t = 20 + 24 = 44 \text{ hrs}$$

$$P_{Detection} = 1 - e^{-\frac{\bar{V}Wt}{A}} = 1 - e^{-\frac{(30.4)(10)(44)}{80145}} = 0.15$$

$$P_{MK} = P_{MK|Detection} * P_{Detection} = 0.52 * 0.15 = \mathbf{0.08}$$

DF-21D Parameters:

$$\text{Max DF21 Range} = 2000 \text{ km} = 1080 \text{ nm}$$

$$\text{Salvo Size} = 20$$

$$P_{MK \text{ Salvo}} = 0.5$$

$$P_{MK} = P_{MK \text{ Salvo}} * P_{Target}$$

Targeting Parameters:

$$\text{Satellite } P_d = 0.3$$

$$\text{ISR UAV Max } P_d = 0.5$$

$$\text{ISR UAV Max Range} = 1000 \text{ nm}$$

$$\text{Maritime Surveillance Ship (MSS) Max } P_d = 0.05$$

$$\text{MSS Range for Constant } P_d = 500 \text{ nm}$$

$$\text{MSS Max Range} = 2000 \text{ nm}$$

Example CVN Risk Calculation at 750 nm continued:

DF-21D Calculations:

$$UAV P_d = Max P_d * \left(1 - \frac{Range}{Max UAV Range}\right) = 0.5 * \left(1 - \frac{750}{1000}\right) = 0.13$$

$$MSS P_d = Max P_d * \left(1 - \frac{Range - Constant Range}{Max MSS Range - Constant Range}\right) = 0.05 * \left(1 - \frac{750 - 500}{2000 - 500}\right) = 0.042$$

$$P_{Target} = (1 - (1 - Satellite P_d) * (1 - UAV P_d) * (1 - MSS P_d)) \\ = (1 - (1 - 0.3) * (1 - 0.13) * (1 - 0.042)) = 0.41$$

$$P_{MK} = P_{MK Salvo} * P_{Target} = 0.5 * 0.41 = \mathbf{0.21}$$

SSK Parameters:

Max SSK Range = 1000 km = 540 nm

Number of SSKs = 30

Search Speed (V) = 3 kts

Search Sector = 100°

Weapons and Search Methods = Same as SSNs

In SSK Range? 750 nm < 540 nm → NO

Land-Based ASCM Parameters:

Max ASCM Range = 280 km = 151 nm

ASCM Max P_{MK} = 0.4

$$ASCM P_{MK} = Max P_{MK} * \left(1 - \frac{Range}{Max ASCM Range}\right)$$

In ASCM Range? 750 nm < 151 nm → NO

Overall Risk Calculations:

$$Overall P_{MK} = (1 - (1 - P_{MK Bombers}) * (1 - P_{MK SSNs}) * (1 - P_{MK DF21s})) \\ = (1 - (1 - 0.02) * (1 - 0.08) * (1 - 0.21)) = \mathbf{0.28}$$

$$Survivability = (1 - P_{MK}) = (1 - 0.29) = \mathbf{0.71}$$

B. EXAMPLE CVN STRIKE POWER CALCULATION AT 750 NM

Aircraft Parameters:

#Embarked = Number of Fighters Embarked = 44

%MC = Percentage of Aircraft Mission Capable = 75%

Average Cruise Speed = 500 kts

Max Range = Max Unrefueled Combat Radius = 600 nm

Payload = 4000 lbs of ordnance

Mission Success Rate = 0.7

Maintenance Parameters:

TAT = Turn Around Time for an UP Aircraft = 1 hr

MT_{sortie} = Maintenance Time per Sortie = 3.4 hrs

MT_{FH} = Maintenance Time per Flight Hour = 0.68 hrs

Tanker Parameters:

Tank_{REQ} = Tankers Required for Launch and Recovery = 6

AddTank = Additional Tankers Req = $\frac{(Range - MaxRange)}{200}$

*Note: AddTank must be rounded up to the nearest unit

Tank_{Ratio} = Fighter to Tanker Ratio = $\frac{2}{2 + AddTankers}$

SGR Calculations:

Flight Time (FT) = $2 * \frac{Distance\ to\ Target}{Average\ Cruise\ Speed} = 2 * \frac{750\ nm}{500\ kts} = 3\ hrs$

Maintenance Time (MT) = MT_{sortie} + MT_{FH} * FT = 3.4 + 0.68 * 3 = 5.44 hrs

Ground Time (GT) = TAT + MT = 1 + 5.44 = 6.44 hrs

No Air Force Tankers Available:

AddTankers = $\frac{750\ nm - 600\ nm}{200\ nm} = 0.75 \rightarrow 1$

Assets = $(\#Embarked * \%MC - Tank_{REQ}) * (Tank_{ratio}) = (44 * 0.75 - 6) * \frac{2}{2 + 1}$
= 18

Sortie Generation Rate = $\frac{24\ hours}{FT + GT} = \frac{24}{3 + 6.44} = 2.54\ Sorties/Day$

Strike Power:

Strike Power = Assets x Payload x Mission Success Rate x SGR

= $18 * 4000 \frac{lbs}{sortie} * 0.7 * 2.54 \frac{sorties}{day} = 128,136\ lbs/day$

APPENDIX E. COST APPENDICES

A. TOTAL FORCE COSTS

Appendix X. depicts the total unit cost of the force structure the team chose to combat the threat in the SCS scenario.

QTY	Platform	Unit Cost	Total Platform Cost
CSG			
1	CVN	\$ 10,111,602,868.94	\$ 10,111,602,868.94
1	CAW	\$ 4,707,043,722.40	\$ 4,707,043,722.40
6	LCS	\$ 724,346,987.15	\$ 4,346,081,922.90
6	DDGs	\$ 2,422,733,346.21	\$ 14,536,400,077.29
2	DDX	\$ 4,023,133,333.33	\$ 8,046,266,666.67
ESG			
1	LHD/LHA	\$ 2,504,337,087.19	\$ 2,504,337,087.19
1	ACE	\$ 393,046,377.60	\$ 393,046,377.60
1	LPD	\$ 1,600,000,000.00	\$ 1,600,000,000.00
1	LSD	\$ 425,901,574.42	\$ 425,901,574.42
4	JHSV	\$ 218,066,000.00	\$ 872,264,000.00
3	SSN	\$ 2,707,100,000.00	\$ 8,121,300,000.00
1	SSGN	\$ 5,913,210,305.48	\$ 5,913,210,305.48
		Total Force Cost	\$ 51,465,851,733.94

B. SURFACE, SUBMARINE, AND AIRCRAFT UNITS COSTS

Appendix B displays the unit costs of each surface vessel, submarine, and aircraft that encompass the force structure used in the SCS scenario.

QTY	Platform	Hull	Nominal Cost	FY\$14
1 CVN			\$ -	\$ -
	Nimitz	CVN68	\$ 4,500,000,000	\$ 5,860,558,425
	Eisenhower	CVN69	\$ 4,500,000,000	\$ 5,860,558,425
	Roosevelt	CVN71	\$ 4,500,000,000	\$ 5,860,558,425
	Lincoln	CVN72	\$ 4,500,000,000	\$ 5,860,558,425
	G Washington	CVN73	\$ 4,500,000,000	\$ 5,860,558,425
	Stennis	CVN74	\$ 4,500,000,000	\$ 5,860,558,425
	Truman	CVN75	\$ 4,500,000,000	\$ 5,860,558,425
	Reagan	CVN76	\$ 4,500,000,000	\$ 5,860,558,425
	Bush	CVN77	\$ 4,500,000,000	\$ 5,860,558,425
	Ford	CVN78	Under Construction	\$ 12,887,200,000.00
	Kennedy	CVN79		\$ 11,498,000,000.00
	Enterprise	CVN80		\$ 13,874,200,000.00
			Average Cost	\$ 10,111,602,869
			Average Ford CVN	\$ 12,753,133,333.33
6 LCS			FY\$10 Cost	
	Freedom Class		\$ 637,000,000	\$ 688,156,646
	Independence Class		\$ 704,000,000	\$ 760,537,329
			Average Cost	\$ 724,346,987
QTY	Platform	Hull	Nominal Cost	FY\$14
6 DDG (A. Burke) FLT I,II,&III				
	Arleigh Burke	DDG51	\$ 1,834,000,000	\$ 2,598,125,686
	Barry	DDG52	\$ 1,834,000,000	\$ 2,548,213,460
	John Paul Jones	DDG53	\$ 1,834,000,000	\$ 2,532,359,390
	Curtis Wilbur	DDG54	\$ 1,834,000,000	\$ 2,477,177,019
	Stout	DDG55	\$ 1,834,000,000	\$ 2,477,177,019
	John S. McCain	DDG56	\$ 1,834,000,000	\$ 2,477,177,019
	Mitscher	DDG57	\$ 1,834,000,000	\$ 2,477,177,019
	Laboon	DDG58	\$ 1,834,000,000	\$ 2,443,950,441
	Russell	DDG59	\$ 1,834,000,000	\$ 2,443,950,441
	Paul Hamilton	DDG60	\$ 1,834,000,000	\$ 2,443,950,441
	Ramage	DDG61	\$ 1,834,000,000	\$ 2,443,950,441
	Fitzgerald	DDG62	\$ 1,834,000,000	\$ 2,443,950,441
	Stethem	DDG63	\$ 1,834,000,000	\$ 2,443,950,441
	Carney	DDG64	\$ 1,834,000,000	\$ 2,412,819,916
	Benfold	DDG65	\$ 1,834,000,000	\$ 2,412,819,916
	Gonzalez	DDG66	\$ 1,834,000,000	\$ 2,412,819,916
	Cole	DDG67	\$ 1,834,000,000	\$ 2,412,819,916
	The Sullivans	DDG68	\$ 1,834,000,000	\$ 2,384,002,678
	Milius	DDG69	\$ 1,834,000,000	\$ 2,412,819,916
	Hopper	DDG70	\$ 1,834,000,000	\$ 2,384,002,678
	Ross	DDG71	\$ 1,834,000,000	\$ 2,384,002,678

Fitzgerald	DDG62	\$ 1,834,000,000	\$ 2,443,950,441
Stethem	DDG63	\$ 1,834,000,000	\$ 2,443,950,441
Carney	DDG64	\$ 1,834,000,000	\$ 2,412,819,916
Benfold	DDG65	\$ 1,834,000,000	\$ 2,412,819,916
Gonzalez	DDG66	\$ 1,834,000,000	\$ 2,412,819,916
Cole	DDG67	\$ 1,834,000,000	\$ 2,412,819,916
The Sullivans	DDG68	\$ 1,834,000,000	\$ 2,384,002,678
Milius	DDG69	\$ 1,834,000,000	\$ 2,412,819,916
Hopper	DDG70	\$ 1,834,000,000	\$ 2,384,002,678
Ross	DDG71	\$ 1,834,000,000	\$ 2,384,002,678
Mahan	DDG72	\$ 1,834,000,000	\$ 2,349,037,709
Decatur	DDG73	\$ 1,834,000,000	\$ 2,349,037,709
McFaul	DDG74	\$ 1,834,000,000	\$ 2,349,037,709
Donald Cook	DDG75	\$ 1,834,000,000	\$ 2,349,037,709
Higgins	DDG76	\$ 1,834,000,000	\$ 2,324,388,662
O'Kane	DDG77	\$ 1,834,000,000	\$ 2,324,388,662
Porter	DDG78	\$ 1,834,000,000	\$ 2,324,388,662
Oscar Austin	DDG79	\$ 1,834,000,000	\$ 2,289,907,889
Roosevelt	DDG80	\$ 1,834,000,000	\$ 2,289,907,889
Winston S. Churchill	DDG81	\$ 1,834,000,000	\$ 2,246,831,400
Lassen	DDG82	\$ 1,834,000,000	\$ 2,246,831,400
Howard	DDG83	\$ 1,834,000,000	\$ 2,246,831,400
Bulkeley	DDG84	\$ 1,834,000,000	\$ 2,246,831,400
McC Campbell	DDG85	\$ 1,834,000,000	\$ 2,241,806,698
Shoup	DDG86	\$ 1,834,000,000	\$ 2,241,806,698
Mason	DDG87	\$ 1,834,000,000	\$ 2,172,536,715
Preble	DDG88	\$ 1,834,000,000	\$ 2,241,806,698
Mustin	DDG89	\$ 1,834,000,000	\$ 2,172,536,715
Chafee	DDG90	\$ 1,834,000,000	\$ 2,172,536,715
Pinckney	DDG91	\$ 1,834,000,000	\$ 2,127,800,189
Momsen	DDG92	\$ 1,834,000,000	\$ 2,127,800,189
Chung-Hoon	DDG93	\$ 1,834,000,000	\$ 2,127,800,189
Nitze	DDG94	\$ 1,834,000,000	\$ 2,076,734,903
James E. Williams	DDG95	\$ 1,834,000,000	\$ 2,127,800,189
Bainbridge	DDG96	\$ 1,834,000,000	\$ 2,076,734,903
Halsey	DDG97	\$ 1,834,000,000	\$ 2,076,734,903
Forrest Sherman	DDG98	\$ 1,834,000,000	\$ 2,039,495,963
Farragut	DDG99	\$ 1,834,000,000	\$ 2,039,495,963
Kidd	DDG100	\$ 1,834,000,000	\$ 1,994,501,471
Gridley	DDG101	\$ 1,834,000,000	\$ 1,994,501,471
Sampson	DDG102	\$ 1,834,000,000	\$ 1,994,501,471
Truxtun	DDG103	\$ 1,834,000,000	\$ 1,931,081,158
Sterett	DDG104	\$ 1,834,000,000	\$ 1,961,694,366
Dewey	DDG105	\$ 1,834,000,000	\$ 1,891,410,461

Stockdale	DDG106	\$ 1,834,000,000	\$ 1,931,081,158
Gravely	DDG107	\$ 1,834,000,000	\$ 1,891,410,461
Wayne E. Meyer	DDG108	\$ 1,834,000,000	\$ 1,931,081,158
Jason Dunham	DDG109	\$ 1,834,000,000	\$ 1,891,410,461
William P. Lawrence	DDG110	\$ 1,834,000,000	\$ 1,844,927,613
Spruance	DDG111	\$ 1,834,000,000	\$ 1,844,927,613
Michael Murphy	DDG112	\$ 1,834,000,000	\$ 1,809,686,260
		Average Cost	\$ 2,422,733,346
2 DDG (Zumwalt)			\$ -
Zumwalt	DDG1000		\$ 4,023,133,333.33
Michael Monsoor	DDG1001		\$ 4,023,133,333.33
Lyndon B. Johnson	DDG1002		\$ 4,023,133,333.33
		Average Cost	\$ 4,023,133,333.33
4 JHSV			\$ -
Spearhead	JHSV-1	\$ 214,000,000.00	\$ 218,066,000.00
Choctaw County	JHSV-2	\$ 214,000,000.00	\$ 218,066,000.00
Milinocket	JHSV-3	Under Construction	
Fall River	JHSV-4	\$ 214,000,000.00	\$ 218,066,000.00
Trenton	JHSV-5	Under Construction	
Brunswick	JHSV-6	Under Construction	
Carson City	JHSV-7	Under Construction	
Yuma	JHSV-8		
Bismarck	JHSV-9		
Burlington	JHSV-10		
		Average Cost	\$ 218,066,000.00
1 LHD			
Wasp (LHD-1)		\$ 822,000,000.00	\$ 1,361,851,560.40
Essex (LHD-2)		\$ 403,000,000.00	\$ 598,759,254.50
Kearsarge (LHD-3)		\$ 353,000,000.00	\$ 510,683,063.00
Boxer (LHD-4)		\$ 341,000,000.00	\$ 474,631,734.60
Bataan (LHD-5)		\$ 731,000,000.00	\$ 979,877,579.40
Bonhomme Richard (LHD-6)		\$ 761,000,000.00	\$ 1,013,000,430.50
Iwo Jima (LHD-7)		\$ 795,000,000.00	\$ 1,017,058,272.70
Makin Island (LHD-8)		\$ 2,300,000,000.00	\$ 2,504,587,703.20
		Average Cost	\$ 1,057,556,199.79
1 LHA			\$ -
Tarawa Class			
Peleliu (LHA-5)		\$ 750,000,000.00	\$ 2,186,094,530.80
America Class			
America (LHA-6)		\$ 3,400,000,000.00	\$ 3,601,029,018.80
Tripoli (LHA-7) (ordered)		Average Cost	\$ 2,893,561,774.80

1 LSD			\$	-
<i>Harpers Ferry Class</i>				
	Carter Hall		\$ 324,200,000.00	\$ 451,248,118.40
	Harpers Ferry		\$ 324,200,000.00	\$ 451,248,118.40
	Oak Hill		\$ 324,200,000.00	\$ 442,400,116.10
	Pearl Harbor		\$ 324,200,000.00	\$ 431,556,819.40
<i>Whidbey Island Class</i>				
	Whidbey Island Class		\$ 250,000,000.00	\$ 469,317,194.40
	Germantown		\$ 250,000,000.00	\$ 456,534,235.80
	Fort McHenry		\$ 250,000,000.00	\$ 444,531,875.20
	Gunston Hall		\$ 250,000,000.00	\$ 414,188,430.80
	Comstock		\$ 250,000,000.00	\$ 398,258,106.50
	Tortuga		\$ 250,000,000.00	\$ 398,258,106.50
	Rushmore		\$ 250,000,000.00	\$ 381,839,028.00
	Ashland		\$ 250,000,000.00	\$ 371,438,743.50
			Average Cost	\$ 425,901,574.42
1 LPD				
Austin Class				
San Antonio Class				
			Average Cost	\$ 1,600,000,000.00
3 SSGN				
	Ohio	SSGN-726		\$ 6,931,143,798.30
	Michigan	SSGN-727		\$ 6,931,143,798.30
	Florida	SSGN-728		\$ 6,931,143,798.30
	Georgia	SSGN-729		\$ 6,931,143,798.30
	Henry M. Jackson	SSGN-730		\$ 6,931,143,798.30
	Alabama	SSGN-731		\$ 5,600,000,000.00
	Alaska	SSGN-732		\$ 5,600,000,000.00
	Nevada	SSGN-733		\$ 5,600,000,000.00
	Tennessee	SSGN-734		\$ 5,600,000,000.00
	Pennsylvania	SSGN-735		\$ 5,600,000,000.00
	West Virginia	SSGN-736		\$ 5,600,000,000.00
	Kentucky	SSGN-737		\$ 5,600,000,000.00
	Maryland	SSGN-738		\$ 5,600,000,000.00
	Nebraska	SSGN-739		\$ 5,600,000,000.00
	Rhode Island	SSGN-740		\$ 5,600,000,000.00
	Maine	SSGN-741		\$ 5,600,000,000.00
	Wyoming	SSGN-742		\$ 5,600,000,000.00
	Louisiana	SSGN-743		\$ 5,600,000,000.00
			Average Cost	\$ 5,913,210,305.48

1 SSN				
	Virginia	SSN-774		\$ 2,707,100,000.00
	Texas	SSN-775		\$ 2,707,100,000.00
	Hawaii	SSN-776		\$ 2,707,100,000.00
	North Carolina	SSN-777		\$ 2,707,100,000.00
	New Hampshire	SSN-778		\$ 2,707,100,000.00
	New Mexico	SSN-779		\$ 2,707,100,000.00
	Missouri	SSN-780		\$ 2,707,100,000.00
	Minnesota	SSN-781		\$ 2,707,100,000.00
	North Dakota	SSN-782		\$ 2,707,100,000.00
	John Warner	SSN-783		\$ 2,707,100,000.00
	Illinois	SSN-784		\$ 2,707,100,000.00
	Washington	SSN-785		\$ 2,707,100,000.00
	Colorado	SSN-786		\$ 2,707,100,000.00
	Indiana	SSN-787		
	South Dakota	SSN-788		
	Deleware	SSN-789		
			Average Cost	\$ 2,707,100,000.00
Carrier Air Wing		Varients		
15	F/A-18F Super Hornets		\$ 66,900,000.00	\$ 69,602,693.10
15	F/A-18E Super Hornets		\$ 66,900,000.00	\$ 69,602,693.10
15	F/A-18C Hornet		\$ 57,000,000.00	\$ 59,302,743.00
15	F/A-18C(N) Hornet		\$ 57,000,000.00	\$ 59,302,743.00
4	E-2C Hawekeye 2000 NP		\$ 80,000,000.00	\$ 87,116,094.00
4	EA-6B Prowler		\$ 52,000,000.00	\$ 54,100,748.00
3	C-2 Greyhound		\$ 38,960,000.00	\$ 42,425,537.80
4	SH-60F/HH-60H Seahawk	MH-60R	\$ 42,900,000.00	\$ 44,633,117.10
Total		MH-60S	\$ 28,100,000.00	\$ 29,235,211.90
75				
			Total Cost of CAW:	\$ 4,707,043,722.40
QTY	Platfrom	Hull	Nominal Cost	FY\$14
Air Combat Element (ACE)		Varients		
6	CH-46 Sea Knights		\$ 6,000,000.00	\$ 10,688,765.00
2	UH-1 Iroquois (Hueys)			\$ 4,700,000.00
3	AH-1 Cobras		\$ 10,700,000.00	\$ 15,728,000.00
3	CH-53 Super Stallions		\$ 24,360,000.00	\$ 36,192,991.20
4	AV-8B Harriers		\$ 27,300,000.00	\$ 40,937,703.50
			Total Cost of ACE:	\$ 393,046,377.60
Additional Assets				
	MQ-8 FireScout			\$ 19,100,000.00
	F-35B			\$ 196,500,000.00
	F-35C			\$ 199,400,000.00
	E-2D Hawkeye			\$ 176,000,000.00
	EA-18 Growler			\$ 68,200,000.00
	Hummingbird			\$ 3,889,111.00
	Tactical TLAM			\$ 1,535,733.00

C. EAB COSTS

Appendix C breaks down the cost breakdown of the EABs used in the report.

EAB (Expeditionary Airbase)		Unit Cost	Total Unit Cost	
6 F-35B	6	\$ 196,500,000.00	\$ 1,179,000,000.00	
2 MQ-8 firescouts	2	\$ 19,100,000.00	\$ 38,200,000.00	
~100 personnel	100	\$ 415.30	\$ 15,158,534.06	
AEW Assets (MH-60S or R)	2	\$ 46,094,877.70	\$ 92,189,755.39	*Average Cost between MH-60S&R
Construction EAB ~ 100M FY\$14			\$ 100,000,000.00	
		Total Cost	\$ 1,232,358,534.06	

D. CVL COSTS

Appendix D displays the cost breakdown of the CVL and the aircraft required to support the SCS scenario.

CVL:	QTY	Unit Cost	Total Unit Cost	
26,000 tons	1	\$ 3,601,029,018.80	\$ 3,601,029,018.80	*Based of USS America
16 F-35B	16	\$ 196,500,000.00	\$ 3,144,000,000.00	
4 MQ-8	4	\$ 19,100,000.00	\$ 76,400,000.00	
3 MH-60R	3	\$ 44,633,117.10	\$ 133,899,351.30	
2 MH-60S	2	\$ 29,235,211.90	\$ 58,470,423.80	
3 AEW Helo	3	\$ 36,934,164.50	\$ 110,802,493.50	*Average Cost between MH-60S&R
		Daily Avg Personnel Cost	Total Annual Cost	
# of Personnel	940	\$ 415.30	\$ 142,490,220.16	
		Total Cost	\$ 7,267,091,507.56	

E. SEA SCOUT COSTS

Appendix E represents the cost breakdown of the Sea Scout Platform and the aircraft required to provide the mission capabilities needed for the scenario.

Sea Scout Platform (TSSE Design w/Alterations)	Qty	Unit Cost (FY\$14)	Total Unit Cost (FY\$14)	Qty	Unit Cost (FY\$14)	Total Unit Cost (FY\$14)
UAV Carrier (TSSE Design)	1	\$ 389,811,658.00	\$ 389,811,658.00	1	\$ 389,811,658.00	\$ 389,811,658.00
HM&E Systems	1	\$ 212,044,128.00	\$ 212,044,128.00	1	\$ 212,044,128.00	\$ 212,044,128.00
Weapon Systems	1	\$ 116,216,135.00	\$ 116,216,135.00	1	\$ 116,216,135.00	\$ 116,216,135.00
Radars/Comms	1	\$ 61,551,395.00	\$ 61,551,395.00	1	\$ 61,551,395.00	\$ 61,551,395.00
Total						
UAV Air Wing						
LRASM	56	\$ 1,300,000.00	\$ 72,800,000.00	0	\$ 1,300,000.00	\$ -
Tactical TLAMs	0	\$ 1,535,733.00	\$ -	56	\$ 1,535,733.00	\$ 86,001,048.00
A160 Hummingbird	21	\$ 3,889,111.00	\$ 81,671,331.00	21	\$ 3,889,111.00	\$ 81,671,331.00
VLS Cells	14	\$ 11,932,490.00	\$ 167,054,860.00	14	\$ 11,935,490.00	\$ 167,096,860.00
		Total Unit Cost	\$ 711,337,849.00		Total Unit Cost	\$ 724,580,897.00

F. ALTERNATIVE COMPARISONS

Appendix F displays the total cost of each alternative for comparison.

Current Force Structure Costs		CVL COST	
\$	51,465,851,733.94	\$	7,267,091,507.56
Current CVN + CAW Costs		SEA SCOUT	
\$	14,818,646,591.34	\$	709,657,849.00
EAB COSTS		\$	724,580,897.00
Small EAB		Strike Capability	# of SEA SCOUTS for CVN/CAW Cost
\$	1,232,358,534.06	LRASM	20.88
		TLAM	20.45

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